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NASA

RL10A-3-3B HIGH MIXTURE RATIO QUALIFICATION PROGRAM

FINAL REPORT

CONTRACT NAS3-22902

by T. Vogel, D. Varella, C. Smith

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Prepared by
United Technologies Corporation
Pratt & Whitney
Government Products Division
P. O. Box 109600, West Palm Beach, Florida 33410-9600

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FOREWORD

This report presents the results of the high mixture ratio qualification testing of the RL10 engine for the Shuttle/Centaur program. The testing was conducted by Pratt & Whitney, Government Products Division (P&W/GPD) of the United Technologies Corporation (UTC) for the National Aeronautics and Space Administration Lewis Research Center (NASA/LeRC) under contract NAS3-22902.

This testing was conducted during the period of March 1985 through January 1986. The testing effort was conducted under the direction of LeRC Space Flight Systems Directorate with Mr. James A. Burkhart as Contracting Officer Representative. The effort at P&W/GPD was carried out under the direction of Mr. Carl Ring, Assistant Project Engineer, and Mr. Tom Vogel, Senior Test Engineer.

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ILLUSTRATIONS (Continued)

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ILLUSTRATIONS (Continued)

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TABLES

SECTION I
OBJECTIVE

The objective of the RL10A-3-3B Engine Qualification Test was to demonstrate the suitability of the RL10A-3-3B engine for space vehicle flight by subjecting it to the testing specified in RL10A-3-3B Model Specification Number 2295 dated 21 February 1986. The applicable section of the specification, paragraph 4.9 is reproduced below.

4.9 Qualification tests. Tests shall be in accordance with the following subparagraphs.

4.9.1 Rocket engine tests. The rocket engine submitted for qualification tests shall have passed the quality conformance test Schedule "B" as specified in 4.10 of this specification, except for item d (Radio Interference). The engine shall be subjected to tests comprised of the requirements listed below. At the discretion of the engine contractor the accomplishment of several conditions listed may be combined in a single firing where practical.

Qualification Requirements

A minimum of 20 firings and not less than 4,500 sec duration including:

Firings	*Conditions*
4	450 sec duration
1	Minimum voltage
1	Maximum voltage
1	Minimum helium pressure
1	Maximum helium pressure
4	Minimum O/F steady-state
4	Maximum O/F steady-state
1	Relight after 2 min
1	Minimum chamber/solenoid temperatures
1	Maximum chamber/solenoid temperatures
4	First burn cooldown limits
4	Relight cooldown limits
1	Start at minimum FPIP and OPIP (and NPSP)
1	Start at maximum FPIP and OPIP (and NPSP)
1	Start at minimum FPIP and maximum OPIP (and NPSP)
1	Start at maximum FPIP and minimum OPIP (and NPSP)
4	Maximum tank pressurization flow at mixture ratio extremes
1	Minimum steady-state fuel NPSP
1	Minimum steady-state oxidizer NPSP
1	Shutdown from minimum O/F
1	Shutdown from maximum O/F
1	Limit Test (Thrust control with no bypass and maximum O/F)*

*This test may be conducted on a representative engine other than the engine submitted for qualification test.

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4.9.1.1 Static leakage test. All hydrogen, oxygen and helium systems of the engine shall be tested for leakage in accordance with the applicable end item test and inspection procedure. Any leakage shall be corrected only in accordance with normal field procedures before resumption of test.

4.9.1.2 Final calibration. The engine shall be subjected to a 450 sec final calibration run. The performance degradation shall be within the contractor's specifications.

4.9.1.3 Additional tests.

4.9.1.3.1 Disassembly. The engines will be disassembled and inspected following the completion of all testing. Component Calibrations Schedules will be performed on components listed in 4.9.3 prior to disassembly.

4.9.1.3.1.1 Rocket engine inspection after disassembly. After disassembly, all parts and components not previously qualified shall be inspected. Any excessively worn, distorted, or weakened parts shall be documented in detail. Calibrations shall be made of all applicable control and control components prior to disassembly.

4.9.1.3.2 Proof pressure. Hydrostatic pressure equal to 1.2 times the nominal pressure at rated thrust plus the difference between nominal working pressure and maximum transient pressure shall be imposed and held for a minimum of 2 minutes. Evidence of leakage, detrimental permanent deformation set while under pressure shall be cause for rejection. All components used on the RL10A-3-3B engine were proof pressure tested during the RL10A-3-3A qualification, therefore satisfying this requirement.

4.9.2 Rocket engine inspection during and after test.

4.9.2.1 Rejection and retest. Whenever there is evidence that the engine is not meeting specification requirements, the difficulty shall be investigated and cause corrected to the satisfaction of the procuring activity, that portion of the test in which the difficulty was encountered shall be repeated.

4.9.3 All components have been previously qualified during the RL10A-3-3 and RL10A-3-3A qualification.

4.9.4 Components inspections during and after test.

4.9.4.1 Rejection and retest. Whenever there is evidence that the components are not meeting specification requirements, the difficulty shall be investigated and cause corrected to the satisfaction of the procuring activity. At the option of the procuring activity, a penalty test shall be conducted.

4.9.4.2 Inspection after test. After completion of tests, the components shall be disassembled for examination of parts. Measurements and photographs shall be taken as necessary to disclose excessively worn, distorted, or weakened parts. Further disassembly may be made at the option of the procuring activity.

4.9.5 Nozzle support plug test. The nozzle support plug test performed for the RL10A-3-3A engine shall satisfy this requirement.

SECTION II
SUMMARY

Due to payload volume advantages which can be achieved by increasing the operating mixture ratio of the RL10 engine, a decision was made to qualify the engine to run at a higher mixture ratio. A program was created to qualify the RL10 engine for operation at 15,000 pounds thrust and a nominal 6.0 to 1 mixture ratio. This model of the engine was designated the RL10A-3-3B.

The Qualification Program included three test series as follows:

Series I	— Hardware durability and limits test — completed in March 1983. The engine completed 23 firings and 4605.7 seconds with 1588.7 seconds at >6.6 mixture ratio.
Series II	— Preliminary qualification test — completed in April 1985. The engine completed 26 firings and 5750 seconds.
Series III	— Qualification test — completed in January 1986. The engine completed 26 hot firings and 5693.4 seconds with 905.9 seconds at 6.7 mixture ratio.

Several changes in engine hardware were required for operation of the RL10A-3-3B engine in the Space Shuttle.

- Dual pressure switch ignition system — provides a redundant switch to indicate the ignition exciter box has retained an acceptable internal pressure.
- Oxidizer flow control — has smaller cooldown flow area to minimize propellant use during cooldown.
- Helium plumbing changes — to accommodate the new oxidizer flow control configuration and to provide partial closure of the fuel pump interstage cooldown valve. The latter provides more efficient cooldown of the fuel pump by using a smaller flow area to dump propellant.

RL10 development engine XR103 was built to run the Qualification Test. During Build 1, on the initial trim run, the engine had unacceptable fuel pump vibration levels and a washout of the silver throat. Since these problems would not be acceptable on a "Green Run" production engine and would require correction, testing was terminated. The engine was rebuilt to run the Qual Test as Build 2 with a new chamber/injector and rebuilt fuel pump.

Build 2 successfully completed the Qualification Test but one anomaly did occur. Run 14.01 did not light and a brief investigation was conducted during Build 2. A separate run program was later created to investigate the problem on another engine. The ignition problem encountered on run 14.01 was found to be related to the small cooldown flow area in the oxidizer flow control and Shuttle Centaur inlet conditions which delayed ignition beyond the test stand no-ignition auto-abort time of 0.49 sec. Subsequent engine testing demonstrated that the no-light encountered during the Qualification Test would have lit on an actual flight. To obtain margin a modified

ignition system must be incorporated if the RL10A-3-3B engine is to be used in the Shuttle Centaur application.

Successful completion of the Qualification Test series verified the durability of the hardware changes and the acceptable operation of the engine at the higher mixture ratio. The engine operated successfully within the conditions specified in Specification 2295 with the exception of the ignition problem. If the RL10A-3-3B engine were to be used on ground launched vehicles with a large cooldown area and inlet conditions similar to the current Atlas Centaur, the engine would be acceptable without further development of the ignition system.

SECTION III
ENGINE ASSEMBLY

A. CONFIGURATION CONTROL

The configuration of the Qualification Test Engine, XR103 Build 1 and 2, was very carefully controlled. This was the same engine (previously P-642024) which was used to qualify the RL10A-3-3A engine. Refer to P&W Report FR-15883 Volume II "RL10A-3-3A Development and Qualification Program, Qualification Test Report." The engine had been in storage since completing the RL10A-3-3A Qual Test and was renumbered according to current procedures. It required updating to the RL10A-3-3B design parts list. The configuration of the engine was established through a process known at Pratt & Whitney as a Functional Configuration Audit. The audit was performed during the assembly and test of engine XR103-1 and -2. The audit provided the following:

- An accurate, complete parts list of all parts in the engine.
- A comparison of the engine parts list with the design parts list.
- Identification and resolution with the government of any differences between the "as built" and design requirements prior to delivery of affected parts to the engine.
- Identification of experimental parts and parts not meeting the minimum inspection level requirements and approval of their use with the concurrence of the government.

The procedure for conducting this audit was as follows:

- All of the parts for use on the engine were reviewed and compared with the RL10A-3-3B design parts list by inspection personnel. This included all parts from the RL10A-3-3A Qual Test Engine P-642024. Parts were inspected for quantity, part number, change letter and inspection marking. Parts which agreed with the bill-of-material and meeting the required level of inspection were entered into the engine parts list (computer) and delivered to the assembly floor. Parts not in agreement with the bill-of-material or inspection requirements were put on hold at the inspection area until the discrepancies were resolved. A Configuration Report (CR) was prepared by inspection personnel identifying the discrepancy. The CR was then provided to RL10 engineering for justification and disposition. The CR was then submitted to the government for concurrence. In certain instances a CR was written by RL10 engineering or configuration management. The approval process is the same for these configuration reports. See Figure III-1 for a typical CR. Following engineering and government concurrence, configuration management enters into the computer the actual part number to be used, including a reference to the CR. The part is then delivered to the assembly floor and the hold status removed.

CONFIGURATION REPORT (CR) NO. 0008

Engine No XR 103-1 Model/Type Test RL10 A-3-3B / Q.T.

P/N VARIOUS Ser No NONE P/S No

Assy No 2185900 Eng Sec Contract NAS 3-22902

Item	Nomenclature	DELIVERED Qty	CL	Remarks	BOM IBM Card			
1	BOLT 419759	2		NO LAB RELEASE				
2	BOLT MS 9061-10	14		" " "				
3	BOLT MS 9033-21	12		" " "				
4	BOLT 383493	3		" " "				

Spec Check

Inspector R Ziesmer Date 6-27-85

Item Ref	C/L	ECR/EC/ER Number	Type	Valid	In Adv	Disposition Reop	Re Insp	RTS	S/C Reid	New Cards Req'd	See Below	Govt App Req'd	DWG CHG Only	By/Date
1-4											✓			

Disposition/Justification: These are parts from RL10A-3-3A Qual Test. Accept for use on XR103-1 based on previous use and engineering review. — TCV 10/25/85

Engineering

Program Manager W.C. Reiz 10/25/85 Gov't [signature] Date 10/28/85

Item	Comment	By/Date
1	ACCEPTABLE FOR USE PER ABOVE. NMA IS 2181414	M. Rupprecht 10-28-85
2	" " " " " , NMA IS A2185900	
3	" " " " " . NMA IS A2185900	
4	" " " " " , NMA IS A2185900	

Configuration Management

FD 317114

Figure III-1. Sample Configuration Report Form

Through this procedure only approved parts are delivered to the engine and an "as built" computerized file is generated. This "as built" parts list may be compared to the design parts list by a computer program. Figure III-2 shows an example of a section of the engine parts list. Part numbers in the engine may not be in the design parts list for the following reasons:

1. The engine received parts in advance of Engineering Change Approval (via Temporary Assembly Procedure or TAP)

2. Special parts were used to provide instrumentation or other special requirements for the Qual Test

3. Parts availability required substitution of equivalent but not identical parts.

Item 1 variations will disappear as the Engineering Changes are approved. Items 2 and 3 variations are considered insignificant in nature and had no impact on Qualification Test results.

B. ENGINE BUILD 1 AND 2

XR103-1 Assembly

Engine P-642024 was received as an RL10A-3-3A model from used stores. This engine was last used in the RL10A-3-3A Qualification Test in December 1981. All components and parts were inspected and those that were not common to the RL10A-3-3B bill of material were cancelled. Parts which are unique to the RL10A-3-3B were then added and the engine was rebuilt as XR103-1. The build was completed 4 December 1985. The build included the following:

Ignition System P/N 2120399 (single pressure switch) configuration was replaced by a dual pressure switch system P/N 2183710, S/N BMT001. This system provides a redundancy of the internal box pressure indicator switch which is required for Shuttle/Centaur use.

LOX Inlet Valve P/N 2077869, CKD 1734, S/N BGP140 was removed and rebuilt per Dwg. 2183704 and CKD 10004. This directed the replacement of the actuator housing cylinder with vendor P/N 5823171-101 which is more resistant to stress corrosion. Also the actuator bellows was replaced with vendor P/N 5842003-101 to qualify a new TIG weld.

Fuel Inlet Valve P/N 2077870, S/N 8L3793 was removed and rebuilt per Dwg. 2185908 and CKD 10006. This directed the replacement of the actuator housing cylinder with vendor P/N 5823171-101 which is more resistant to stress corrosion. Also the actuator bellows was replaced with vendor P/N 5842003-101 to qualify a new TIG weld.

Oxidizer Flow Control P/N 2139014, S/N 600400 was removed and cancelled and replaced by OFC P/N 2119340 per TAP 5478. This valve is an RL10A-3-3 type. This configuration has a smaller cooldown flow area which provides less propellant use during the cooldown cycle.

Gimbal P/N 2118942, S/N BIK603 was replaced due to stress corrosion cracks found around some of the assembly bolt holes. Gimbal P/N 2118942, S/N BMC94 was pulled from finished stores and sent to be reworked to incorporate PLO 11236 and SL 240445. This directed the heat treating and inspection of the gimbal to prevent stress corrosion cracks. Reworked gimbal P/N 2186814.

FILE: XR103-2 SPECHECK A1 P R A T T A N D W H I T N E Y A I R C R A F T PAGE 00014

APD	2057431	2119339	A001 001		WASHER-BELLOWS SUPT O				FLT.	11/21/85SC40	A377658
APD	2057508	2119339	B001 001		SEAL RING-METAL&PLAST	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2059308	2119339	D001 001		VALVE ASSY-OXD FLOW C			BEZ-345	FLT.	06/21/85SC16	ORIDECK
APD	2059309	2119339	C001 001		GUIDE-OXD FLOW CTRL I		CL-2		FLT.	06/21/85SC16	ORIDECK
APD	2059310	2119339	B001 001		SEAT-OXD FLOW CTRL IN				FLT.	06/24/85SC16	ORIDECK
APD	2059317	2119339	C001 001		RESTRICTOR-FLUID FLOW		CL-7	CKD-1732	EI	FMLB06/24/85SC16	ORIDECK
APD	2061594	2119339	E001 001	E	BELLOWS-METAL,OXIDIZE	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2061939	2119339	B001 001		LOCK-OXD FLOW CTRL VV				FLT.	11/21/85SC40	A377518
APD	2064279	2119339	F001 001		VALVE-OXIDIZER FLOW C		CL-3	BHR-152	FLT.	06/21/85SC16	ORIDECK
APD	2069713	2119339	A001 001		RETAINER-GEARSHAFT OX	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2069714	2119339	NC002 002		ADJUSTER-OXIDIZER FLO	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2069715	2119339	NC002 002		CAP-OXIDIZER FLOW CON				FLT.	06/25/85SC16	ORIDECK
APD	2069716	2119339	NC004 004		GASKET-.200 ID X.375				FLT.	11/19/85SC40	A136249
APD	2069807	2119339	NC002 002		NUT-PLAIN HEX .190-24	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2070298	2119339	A001 001		CAP-MACHINE THREAD 1.				FLT.	06/11/85SC16	ORIDECK
APD	2071376	2119339	C001 001		GASKET-OXIDIZER FLOW				FLT.	12/19/85SC16	A95038
AND	2071385	2119339	A001 001		STOP-OXZ FLOW CONTROL			BGP351	FLT.	06/24/85SC16	ORIDECK
APD	2092389	2119339	A001 001		GEAR RACK-OXIDIZER FL				FLT.	06/24/85SC16	ORIDECK
APD	2092391	2119339	A001 001		GEARSHAFT-SPUR OXZ FL			AFG321766	FLT.	06/24/85SC16	ORIDECK
APV	2092826	2119339	B001 001		ADAPTER-STR TUBO .375						
APD	2104898	2119339	NC001 001		WASHER-KEY .3275 ID X	0040	ACCEPTABLE TAP 5478 ADD			12/19/85SC06	A377647
APD	2104899	2119339	A001 001		METERING PLUG-OXZ FLO	0040	ACCEPT BLD1 A377647 TAP		FLT.	12/17/85SC06	A377523
APD	2106258	2119339	C001 001	C	SEAT-OXZ FLWC & INLET	0503	TAP5478		FLT.	11/21/85SC40	A377631
ANV	2110905	2119339	A001 001		SEAL ASSY-OXIDIZER FL						
APD	2111490	2119339	NC001 001		WASHER-FLAT,.850 X1.3	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2111491	2119339	NC001 001		SPRING-HELICAL,CPN,1.	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	2144613	2119339	NC001 001		HOUSING-OXIDIZER FLWC	0046	TAP5478,CR503 ATR 36	ATR337		12/18/85SC06	A377630
APD	2172281	2119339	NC002 002		PIN-STR,HDLS,.0625 DI	0040	ACCEPTABLE			12/19/85SC06	A377647
APD	326190	2119339	D001 001		RING-LOCK 1.2565X.085	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APV	474107	2119339	NC001 001		PIN-STR HEADED .125 D						
APD	480453	2119339	NC001 001		PIN-STR HEADLESS .062				FLT.	11/20/85SC40	A377647
APD	480490	2119339	A001 001		GASKET-.365 ID X .615	0503	QTY 2 TO 1 TAP5478,CR40			12/05/85SC4065565	A136249
APD	480492	2119339	B002 002	A	GASKET-.660 ID X .789	0040	ACCEPTABLE			12/19/85SC06	A136249
APD	480499	2119339	NC001 001		WASHER-KEY,2.380 ID X	0040	ACCEPTABLE			12/19/85SC06	A377647
APD	480551	2119339	NC001 001		INVERTED NUT-SPANNER				FLT.	06/24/85SC16	ORIDECK
APD	480580	2119339	NC001 001	A	GASKET-.990 ID X 1.21	0040	TAP 5478		FLT.	02/26/86SC61	A377513
APD	480582	2119339	NC001 001		WASHER-THRUST .8565 X	0023	ACCEPT-PREVIOUS BLD		FLT.	11/11/85SC40	ORIDECK
APD	AS100027	2119340	NC0AR 0AR		LOCKWIRE-.025 DIA				EI	FMLB06/04/85SC16	ORIDECK
AND	2059354	2119340	B001 001		VALVE ASSY-PURGE CHEC			AZX-419	EI	FMLB06/04/85SC16	ORIDECK
APD	2071661	2119340	A002 002		SCREW-MACHINE .164-32				EI	FMLB06/04/85SC16	ORIDECK
APD	2106279	2119340	A001 001	B	PLATE-IDENT OXZ FLOW	0064	OK-NON FUNCTIONAL		EI	FMLB02/26/86SC61	ORIDECK
ANV	2119339	2119340	F001 001		VALVE ASSY-OXIDIZER F	0503	TAP5478				
APD	480490	2119340	A001 001		GASKET-.385 ID X .615				EI	FMLB06/04/85SC16	ORIDECK
A V	2077689	2126523	NC001 001		SHROUD-OXIDIZER PUMP						
A V	2126587	2126523	NC001 001		INDUCER-OXIDIZER PUMP						
A D	2099454	2126524	NC001 001		SHROUD-OXIDIZER PUMP				FLT.	05/28/85SC16	ORIDECK
A D	2126588	2126524	NC001 001		IMPELLER-OXIDIZER PUM				FLT.	05/28/85SC16	ORIDECK
A D	AS125708	2129971	NC009 009		RIVET-SOLID,UNIV HD,.				FLT.	05/28/85SC16	ORIDECK
A D	2099511	2129971	A001 001		TURBINE STATOR-TURBOP				FLT.	05/28/85SC16	ORIDECK
A D	2100363	2129971	A001 001		SHROUD-TURBINE STATOR				FLT.	05/28/85SC16	ORIDECK
A D	2100374	2129971	NC009 009		PLUG-TURBINE STATOR,1				FLT.	05/28/85SC16	ORIDECK
AO	2070916	2130720	E 001		SEAL-FACE .8975 X1.62			BIM-868	(IC)		
AO	2106152	2130720	A 001		SEAL-FACE .890 X1.625				(IC)		
A D	2095152	2131534	NC001 001		PIN-STRAIGHT HEADLESS				FLT.	05/28/85SC16	ORIDECK
A D	2095153	2131534	NC004 004		PIN-STRAIGHT HEADLESS				FLT.	05/28/85SC16	ORIDECK

Figure III-2. Sample Page from Engine Parts List

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Transducer Box P/N 2144547, S/N BIS569 was reworked per SL 239303. This drawing directed the modification of the box to install three more mounts for instrumentation and two fiberglass heat shields for the Shuttle Centaur configuration. Reworked transducer box P/N 2185705.

Since the original thrust control had been diverted for use in the RL10 development program, Thrust Control Valve P/N 2105497, S/N 607147 was assembled from new and used development parts. Upon completion of build the valve was sent to test per RL10A-3-3A CCS (Component Calibration Schedule). After satisfactory completion of test the valve was adjusted to the RL10A-3-3B thrust setting. This was accomplished by adjusting the PC adjustment knob seven turns in a counterclockwise direction (downtrim from 16.5K to 15K thrust).

Jacket Inlet Line P/N 2118223 had a Class 4 orifice installed to meet RL10A-3-3B requirements. This orifice replaced the Class 1 orifice which had been used for the RL10A-3-3A Qual Test.

A new Chamber/Injector Assembly was used since the original chamber had been used in the RL10 development program. Chamber P/N 2180696, S/N ACB872 was pulled from finished stores and was the current bill-of-material part number with silver throat insert.

The Fuel Pump P/N 2135710, S/N 600524 was rebuilt using most of the parts from P-642024. The same fuel pump shaft with a new drive gear was used. In addition all new bearings were installed and a new housing temperature probe was used to replace the original probe which had been diverted to the RL10 development program.

The Oxidizer Pump P/N 2181415 S/N 600524 was rebuilt using most of the parts from P-642024. New parts included bearings, idler gear, gearshaft assembly, inducer, one seal plate and a new housing temperature probe. The original probe had been diverted to the RL10 development program.

All of the remaining components from P-642024 were sent for CCS to verify that they were still acceptable for engine test after the long storage time. All passed their respective CCSs and were used on the engine.

Table III-1 lists the major components installed on the engine Build 1.

All parts which were added to the engine were processed through spec check for verification of compliance with the latest RL10A-3-3B design requirements. Any parts not conforming were documented on a CR as described in Section IIIA.

Several Engineering Changes were in process at the time of the final engine build. All of these changes were documented on TAPs (Temporary Assembly Procedures). These TAPs allowed the engine build to continue in advance of the changes. The following TAPs were incorporated:

TAP 5476A. This procedure enables the interstage cooldown valve to partially close at fuel prestart rather than at start. This provides less propellant useage during cooldown.

Table III-1. *Major Components Installed on Build 1*

Nomenclature	*Part No.*	*Serial No.*
Injector and Thrust Chamber Assy	2180696	ACB872
Injector	2131256	BMC57
Turbopump Assembly	2181414	600524
Fuel Pump	2135710	600524
Oxidizer Pump	2181415	600524
Fuel Inlet Shutoff Valve	2185908 CKD10006	8L3793
Oxidizer Inlet Shutoff Valve	2183704 CKD10004	BGP140
Main Fuel Shutoff Valve	2112399	600523
Interstage Cooldown Valve	2183571	600520
Pump Discharge Cooldown Valve	2106435	600523
Fuel Prestart Solenoid Valve	2085703	600574
Oxidizer Prestart Solenoid Valve	2085703	600578
Start Solenoid Valve	2085703	600580
Thrust Control	2105497	607147
Oxidizer Flow Control	2119340	BKW759
Oxidizer Igniter Valve	2075301	626127
Fuel Pump Housing Temperature Sensor	2114950	BLG466
Oxidizer Pump Housing Temperature Sensor	2114950	BLG467
Ignition System	2183710	BMT001
Turbine Inlet Temperature Sensor	2100815	BIH250
Speed Sensor	2064388	4529-008
Gimbal	2186814 SL240445	BMC94

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TAP 5477A. This procedure removed the orifice in the Fuel Inlet Valve and installed a (0.045) orifice in the fuel prestart solenoid. In addition helium plumbing was changed to supply the start solenoid helium from the oxidizer prestart solenoid instead of the fuel prestart solenoid. This configuration provides a faster closing of the inlet valve to reduce backflow into the liquid hydrogen inlet supply duct.

TAP 5478. This procedure simplifies TAP 5476A and provides an RL10A-3-3 Type OFC P/N 2119340 (with no bypass valve). Associated helium plumbing was changed to accompany the valve change.

TAP 5479. This procedure adds a bracket and associated clip to support a helium tube left unsupported when TAP 5478A was incorporated. This TAP was incorporated after testing had begun.

The engine weight was 302.7 lb; this compares to the specification requirement of 310 lb for the engine in the proposed Model Spec. No. 2295.

Engine XR103-1 was delivered to E-6 test stand on 4 December 1985.

XR103-1 Teardown

The engine was pulled from E-6 stand on 6 December 1985 after the initial trim run, HR 01.01 (not part of the qualification test). The engine experienced high turbopump vibrations and a severe washout of the silver throat during the trim run and was returned to RL10 assembly for teardown, repair and reassembly.

Teardown Summary

The engine was disassembled into major components to allow disassembly of the fuel pump and replacement of the chamber. The turbopump was split and the fuel pump was completely disassembled. The following items were noted:

- The inducer blades were rubbed slightly and a corresponding rub pattern was seen in the impeller housing.

- The first stage impeller tips showed a moderate rub and a corresponding wear pattern was seen in the impeller housing. The inducer rub and blade tip rub were in areas that were worn from the previous build of the pump (P-2024).

- The idler gear and fuel pump gear showed an uneven wear pattern. The coating was worn through to the metal surface for approximately half the tooth width. The wear was light, within the range of normal wear for these parts and was acceptable for use as is.

- The larger seal seat on the fuel pump shaft had a ding at the OD corner which locally cracked and separated the chrome plate. The damage was outside of the carbon seal seating area and the shaft was considered acceptable for reuse as is.

- Light rubbing was noted on the knife edges of the turbine rotor and on the OD seal lands of the exit stator but may have existed from earlier running.

- Because of the fuel pump vibration problem the pump impellers and turbine were sent for check balance and the shaft was sent to have the ID bores checked for concentricity and then check balance. The turbine rotor and second stage impeller checked within limits. The first stage impeller was rebalanced without check balance since the rotor had some rub and one balance weight could not be removed. The shaft bore concentricities were out of limits and the shaft was replaced.

- All three locking pins on the fuel pump housing temperature probe had been torn out — apparently when the test cable was disconnected. The probe required replacement for the next build but is probably repairable.

- The silver throat was washed out for approximately two inches around the circumference and down to the tubes in one area. See Section V, Figures V-11 and V-12. This washout was attributed to a poor bond during manufacturing. No other major problems were noted with the chamber. The chamber was replaced for Build 2. Pre-run photos of the silver throat are shown in Section V, Figures V-6 through V-10.

XR103-2 Assembly

Assembly of XR103-2 was completed on 17 December 1985.

The engine was assembled per standard RL10A-3-3B Operation Sheets with P&W and government inspection witness. All government and spec check inspection requirements were met. With the exception of expendable items and those items listed below, all parts from Build 1 were reused. Table III-2 lists parts installed in Build 2.

Table III-2. *Parts Installed on Build 2*

Part Name	*Part Number*	*Comments*
Chamber/Injector	2180696 S/N ACB 888	New Chamber from P642048.
Fuel Pump Housing Temperature Probe	2114950 S/N BLG 483	New from Flight Stores Model No. 177 BR.
Bearing, Fuel Pump Rear	2069342 S/N BID 452	New from Flight Stores.
Bearing, Fuel Pump Front	2069343 S/N BID 397	New from Flight Stores.
Fuel Pump Shaft Assembly	2099978 S/N BEZ 738	From Development Stores. Had best bore concentricities of available shafts. (0.0001 over limit)
2nd Stage Impeller Spacer	2109360 Cla. 2	Changed to get correct 1st-stage impeller clearance.
Fuel Tank Pressurization Adapter	2183614	From Flight Stores replaced Build 1 adapter which had incorrect orifice size.

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XR103-2 was delivered to E-6 test stand on 17 December 1985. Photos of the engine as tested are shown in Figures III-3, 4, 5, 6 and 7.

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Figure III-3. RL10A-3-3B Qualification Engine

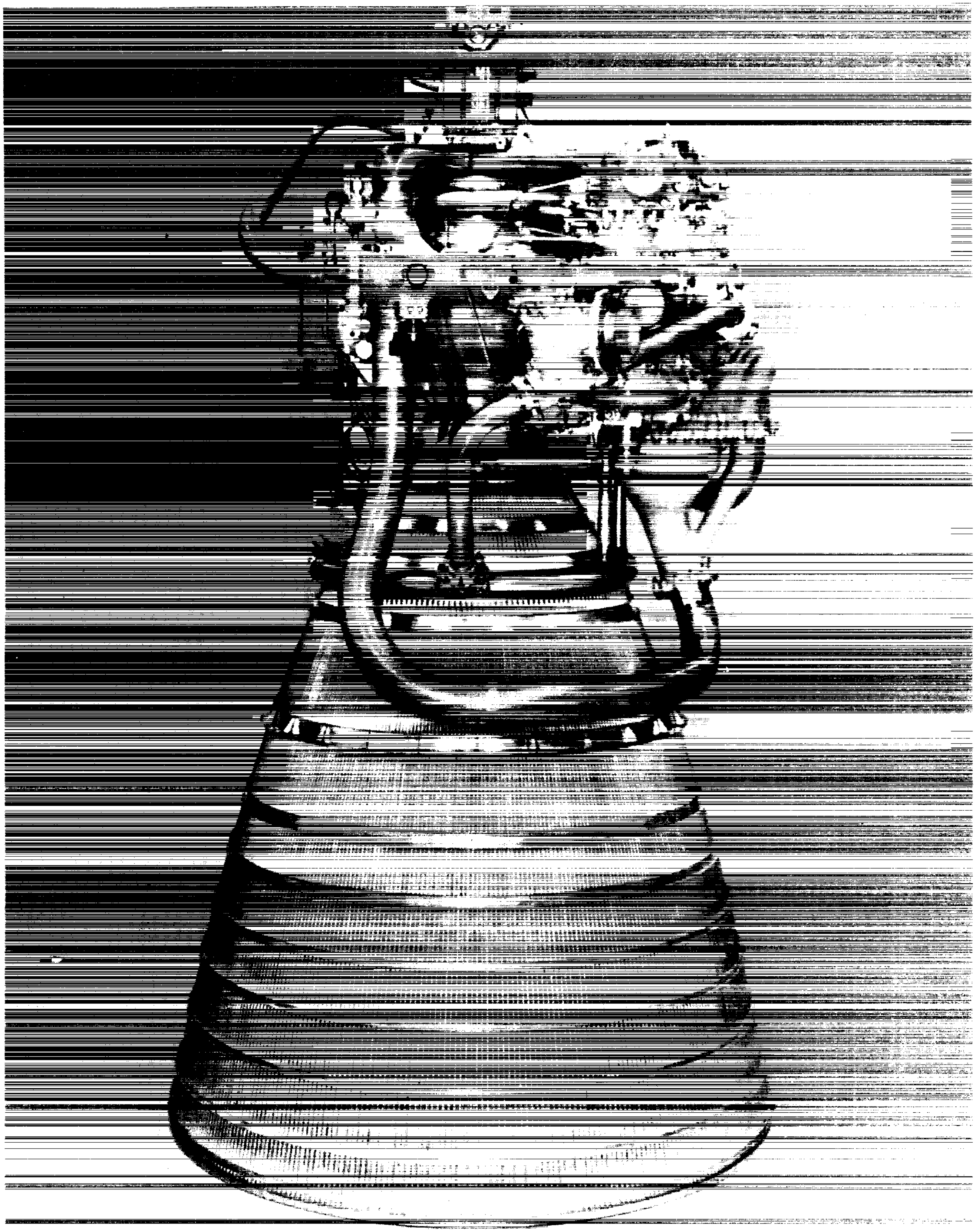
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Figure III-4. RL10A-3-3B Qualification Engine

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Figure III-5. RL10A-3-3B Qualification Engine

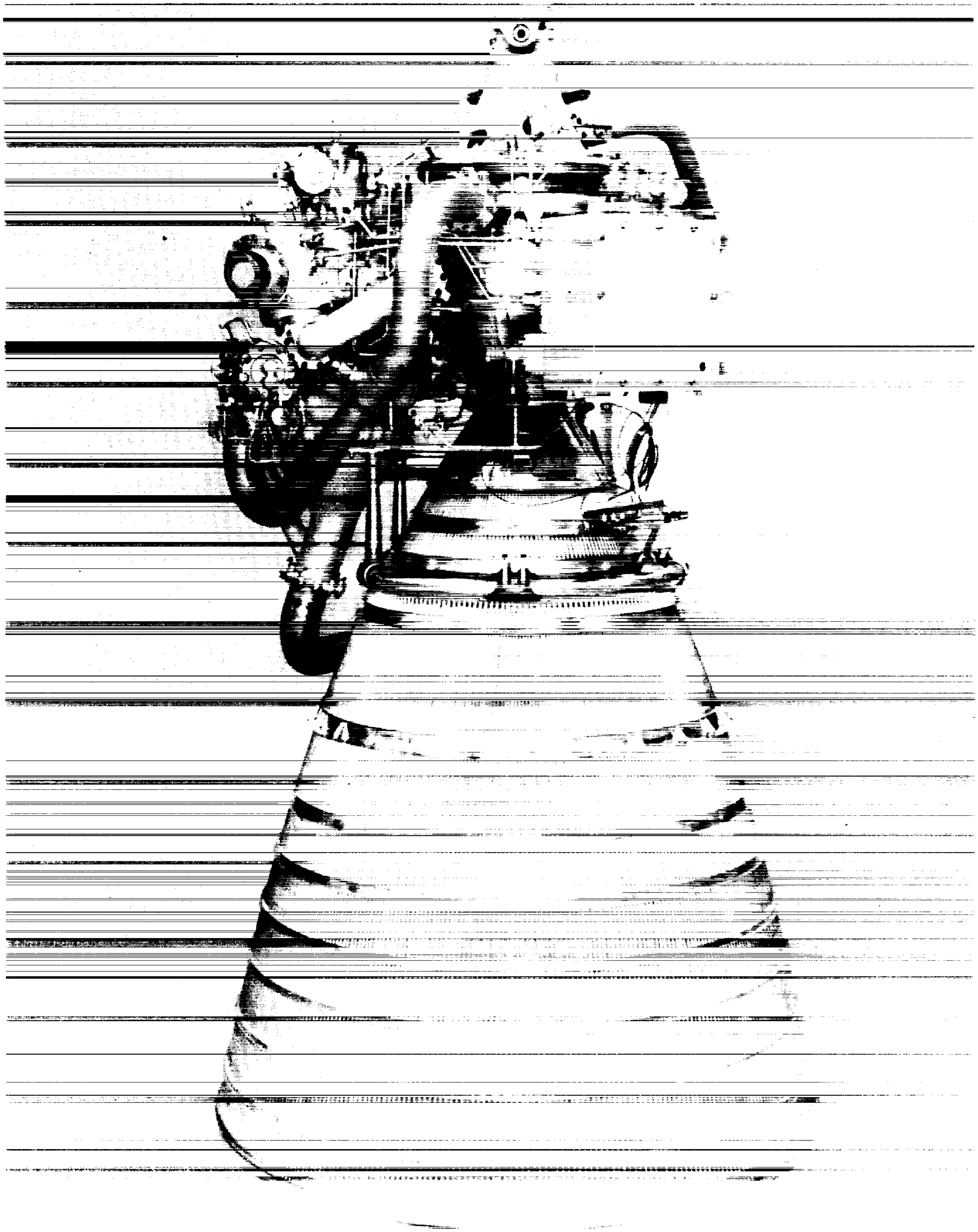

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Figure III-6. RL10A-3-3B Qualification Engine

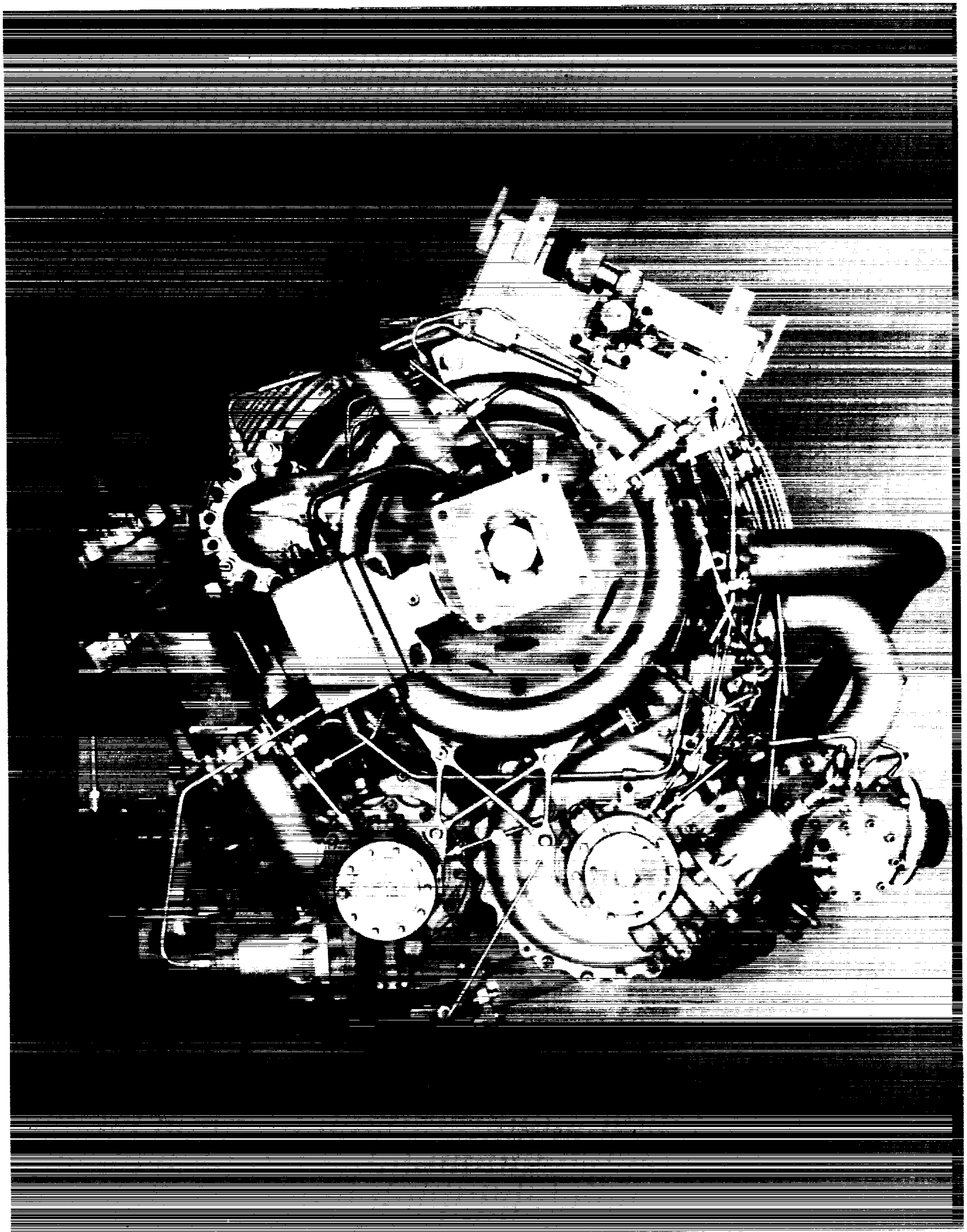

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Figure III-7. Top View of RL10A-3-3B Qualification Engine

SECTION IV
ENGINE TEST RATIONALE

A. BACKGROUND

The RL10A-3-3B engine model was derived from the qualified RL10A-3-3A engine model. Changes in the RL10A-3-3B model consist of the following:

- Operation at nominal mixture ratio of 6.0 instead of 5.0
- Operation at reduced thrust level of 15,000 pounds instead of 16,500 pounds
- Operation over a wider range of propellant inlet conditions
- Increased cooldown times with smaller flow areas in both fuel and oxidizer systems to provide more efficient cooldown.

The RL10A-3-3A Qualification Test was conducted on two engines:

Engine P642024

- *20 firings, 4500 seconds* — verify specification limits and engine durability

Engine FX149

- *Structural limits test* — verify safe operation with failed thrust control.

The RL10A-3-3B Qualification Test was also conducted on two engines in a similar fashion:

Engine XR103-2

- *20 firings, 4500 seconds* — verify specification limits and engine durability

Engine XR102-2

- *Structural limits test* — verify safe operation with failed thrust control.

The highest structural loads on the chamber would occur if the thrust control failed at maximum mixture ratio. This situation was successfully demonstrated on XR102-2. The test is discussed in Section VI.

B. TEST PLAN

Prior to testing a detailed test plan was submitted to NASA for approval as required under Contract NAS3-22902. The Test Plan follows.

QUALIFICATION TEST PLAN

RL10A-3-3B ENGINE

Prepared under Contract NAS3-22902
for
NASA-Lewis Research Center
Cleveland, Ohio 44135

Prepared by
United Technologies Corporation
Pratt & Whitney
Government Products Division
P.O. Box 2691, West Palm Beach, Florida 33402

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QUALIFICATION TEST PROCEDURE FOR RL10A-3-3B ENGINE

1.0 TEST OBJECTIVE

The objective is to conduct a Qualification Test in accordance with Pratt & Whitney Aircraft Preliminary Model Specification No. 2295 dated 2 Feb. 1983 to demonstrate the suitability of RL10A-3-3B engines for use in the Shuttle Centaur Space Transportation System.

2.0 GENERAL

2.1 An engine qualification test will be performed on an RL10A-3-3B engine acceptable to the Government. Configuration control will be in accordance with the contractor's procedures and PMI 5009 for the qualification test engine. The engine and components will be assembled and tested in accordance with RL10A-3-3A/B production procedures. (Preliminary procedures may be used.)

2.2 Prior to starting the Qualification Test the engine must complete an acceptable Trim and Trim Repeat Test per the RL10A-3-3A/B TIS.

2.3 Engine testing will be accomplished in E-6 test stand per the applicable rocket engine test procedure. Notification of individual test schedules will be provided to the Government office at least two hours prior to the start of each specific test. Presence of a Government office representative is not required while tests are being conducted.

2.4 The Qualification Test shown on Table I can be accomplished in any sequence determined by Project Engineering. Table I is a suggested run sequence only.

2.5 Failure of the engine to meet requirements of the specification shall be investigated and corrected in accordance with paragraph 4.9.2.1 of Specification No. 2295.

2.5.1 Part failure, adjustment and replacement for the qualification test engine will be in accordance with paragraph 4.8.9 of Model Specification No. 2295.

2.6 Automatic data recording equipment will be utilized to record engine transient and steady state data as shown on the Test Instruction Sheet (TIS). This is the same instrumentation that is used for production engine testing. Vibration instrumentation in accordance with the requirements of the Test Instruction Sheet will be utilized. Other specialized instrumentation will be requested by Project Engineering.

3.0 ENGINE TEST

The engine shall be subjected to a series of tests to meet the requirements of paragraph 4.9.1 of the specification. Test conditions are described in Tables I and II. These tests will be preceded and

followed by static leakage tests. Leak tests may be omitted between firings to allow rapid engine turnaround when it is desired to make multiple firings in a short period of time or if the mylar insulation blanket is installed. A minimum of 20 firings and a minimum total running time equal to 4500 seconds shall be accumulated on this engine prior to final static leakage tests. Satisfactory engine condition will be verified by a post-test calibration firing. The engine will then be disassembled.

3.1 Static leakage test - All hydrogen, oxygen and helium systems of the engine shall be tested for leakage in accordance with the applicable End Item Test and Inspection Procedure, PEP63. Any leakage shall be corrected only in accordance with normal field procedures and/or TIS before resumption of test.

3.2 Post-test calibration firing - The engine shall be subjected to a 450 second final calibration run. The performance degradation shall be within the contractor's specifications.

3.3 Disassembly - The engine will be disassembled and visually inspected (some dimensional inspection for documentation may be required). Some components may be tested for information purposes if requested by Project Engineering.

4.0 QUALITY ASSURANCE

4.1 All testing, unless otherwise specification herein, will be in accordance with the RL10A-3-3A/B Test Instruction Sheet.

4.2 The data evaluation of the engine test will be completed in a timely manner. All summarized test data will be presented for review to Quality Engineering and the Government representative on an RL10 Engine Performance Summary Form.

Representatives of Project Engineering (or designees) will conduct a preliminary data review after each test. From this preliminary review and if the test objectives are met, authority for further engine testing will be given. If the test objectives are not met but can be accomplished in combination with another test in the series, testing can proceed without repeating the specific test.

*5.0 LIMIT TEST

The limit test, thrust control with no bypass (vented thrust control) and maximum O/F, will be performed on a representative development engine selected by Project Engineering. This test may be done before or after the Engine Qualification Testing.

* The Limit Test was completed during the prequalification test series on XR102-2 on 4/12/85.

6.0 REPORT

Following successful completion of the engine qualification tests, a report shall be prepared in accordance with paragraph 4.8.5 of the specification and delivered to the Government.

TABLE II. QUALIFICATION REQUIREMENTS
(PER SPECIFICATION NO. 2295 SECTION 4.9.1)

A minimum of 20 firings and not less than 4,500 sec duration including:

Qualification Test No.	No. of Firings	Condition
1, 5, 10, 15	4	450 sec duration
1	1	Minimum voltage
5	1	Maximum voltage
10	1	Minimum helium pressure
15	1	Maximum helium pressure
1, 5, 10, 15	4	Minimum O/F steady-state
1, 5, 10, 15	4	Maximum O/F steady-state
4	1	Relight after 2 min
*2	1	Minimum chamber temperatures
6	1	Minimum solenoid temperatures
3	1	Maximum chamber/solenoid temperatures
6, 8, 11, 13	4	First burn cooldown limits
7, 9, 12, 14	4	Relight cooldown limits
6	1	Start at min FPIP (and NPSP) and min OPIP (and NPSP)
8	1	Start at max FPIP and max NPSP at that pressure and max OPIP (and NPSP)
11	1	Start at min FPIP (and NPSP) and max OPIP (and NPSP)
13	1	Start at max FPIP and max NPSP at that pressure and min OPIP (and NPSP)
1, 5, 10, 15	4	Tank pressurization flow at mixture ratio extremes
5	1	Minimum steady-state fuel NPSP
10	1	Minimum steady-state oxidizer NPSP
1	1	Shutdown from minimum O/F
5	1	Shutdown from maximum O/F

* Minimum chamber temperature conditions will be obtained by running a rapid relite test instead of precooling the thrust chamber to a specified "Cold Jacket" temperature. The rapid relight more closely simulates actual conditions which occur during engine operation in space.

TABLE I

QUALIFICATION TEST PROGRAM

Test No.	Test Type	Planned Duration (Secs.)	Start Inlets FPIP	Start Inlets FPIT	Start Inlets OPIP	Start Inlets OPIT	Prestart (Sec) Fuel	Prestart (Sec) LOX	Steady State Inlets FPIP	Steady State Inlets FPIT	Steady State Inlets OPIP	Steady State Inlets OPIT	Remarks
1	RL10 A-3-3B Trim	250	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 -0	38.5±.5	41.0±1	175.0±2	Trim run per the RL10 A-3-3A/B TIS
2	Trim Repeat	450	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 -0	38.5±.5	41.0±1	175.0±2	Trim repeat run with P.U. excursion per TIS
3	Qual Test #1	450	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 -0	38.5±.5	41.0±1	175.0±2	Min. voltage to solenoids/igniter at start (17-20 VDC). Tank press. flow at min. and max. M.R., shutdown at min. M.R.
4	Qual Test #2	150	27.5±.5	38.5±.5	44.0±2	176.0±2	5	5	---	---	---	---	Rapid relight 30 seconds after shutdown of previous run. (min. chamber temperature)
5	Qual Test #3	150	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	---	---	---	---	Preheat thrust chamber to FTIT=620°-675°R and MWST 600°R at prestart. Preheat solenoids to 620°-675°R at prestart.
6 ◇	Qual Test #4	150	27.5±.5	38.5±.5	44.0±2	176.0±2	5	5	---	---	---	---	Relight 2 minutes after shutdown of previous run.

NOTE: For all runs prestart times are maximum. All other parameter limits are targets unless further specified in the remarks column.

◇ - Can follow any run.

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TABLE I

QUALIFICATION TEST PROGRAM

Test No.	Test Type	Planned Duration (Secs.)	Start Inlets FPIP	Start Inlets FPIT	Start Inlets OPIP	Start Inlets OPIT	Prestart (Sec) Fuel	Prestart (Sec) LOX	Steady State Inlets FPIP	Steady State Inlets FPIT	Steady State Inlets OPIP	Steady State Inlets OPIT	Remarks
7	Qual Test #5	450	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 −0	38.5±.5	41.0±1	175.0±2	Start with max. voltage to solenoids/igniter (30-33 VDC), P.U. excursion with tank press. flow at min. and max. M.R. Min. steady state fuel NPSP (2.5-3.0 PSID), shutdown at max. M.R.
8*	Qual Test #6	150	4.6+0NPSP −1	38.5±.5	7.5+0NPSP −1	171.6±.5	45	250	25.5±.5	---	41.0±1	---	1st burn cooldown limits, min. fuel and min. oxidizer pressure and NPSP at start. Precool solenoids to 250-395°R at prestart.
9△*	Qual Test #7	150	4.6+0NPSP −1	38.5±.5	7.5+0NPSP −1	171.6±.5	5	5	25.5±.5	---	41.0±1	---	Relight cooldown limits, min. fuel and min. oxidizer pressure and NPSP at start.
10*	Qual Test #8	150	8.5+0NPSP −0	39.3±.5	20.5+1NPSP −0	185.5±.5	36	165	---	---	---	---	1st burn cooldown limits, max. fuel pressure and NPSP at that pressure and max. oxidizer pressure and NPSP at start.

* Mylar Blanket Required
△- Rapid Relight

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TABLE I

QUALIFICATION TEST PROGRAM

Test No.	Test Type	Planned Duration (Secs.)	Start Inlets FPIP	Start Inlets FPIT	Start Inlets OPIP	Start Inlets OPIT	Prestart (Sec) Fuel	Prestart (Sec) LOX	Steady State Inlets FPIP	Steady State Inlets FPIT	Steady State Inlets OPIP	Steady State Inlets OPIT	Remarks
11△*	Qual Test #9	150	8.5+1NPSP -0	39.3±.5	20.5+1NPSP -0	185.5±.5	5	5	---	---	---	---	Relight cooldown limits, max. fuel pressure and NPSP at that pressure and max. oxidizer pressure and NPSP at start.
12	Qual Test #10	450	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 -0	38.5±.5	41.0±1	175.0±2	Start with min. helium supply press. (415-440 psia), P.U. excursion with tank press. flow at min. and max. M.R., min S/S oxidizer NPSP (4.7-5.2 PSID).
13*	Qual Test #11	150	4.6+0NPSP -1	38.5±.5	20.5+1NPSP -0	185.5±.5	45	165	25.5±.5	---	---	---	1st burn cooldown limits, min. fuel and max. oxidizer pressure and NPSP at start.
14△*	Qual Test #12	150	4.6+0NPSP -1	38.5±.5	20.5+1NPSP -0	185.5±.5	5	5	25.5±.5	---	---	---	Relight cooldown limits, min. fuel and max oxidizer pressure and NPSP at start.
15*	Qual Test #13	150	8.5+1NPSP -0	39.3±.5	7.5+0NPSP -1	171.6±.5	36	250	---	---	41.0±1	---	1st burn cooldown limits, max. fuel pressure and NPSP at that pressure and min oxidizer pressure and NPSP at start.

* Mylar Blanket Required
△ - Rapid Relight

TABLE I

QUALIFICATION TEST PROGRAM

Test No.	Test Type	Planned Duration (Secs.)	FPIP	Start Inlets FPIT	Start Inlets OPIP	OPIT	Prestart (Sec) Fuel	Prestart (Sec) LOX	FPIP	Steady State Inlets FPIT	Steady State Inlets OPIP	OPIT	Remarks
16△	*Qual Test #14	150	8.5+1NPSP −0	39.3±.5	7.5+0NPSP −1	171.6±.5	5	5	---	---	41.0±1	---	Relight cooldown limits, max. fuel pressure and NPSP at that pressure and min. oxidizer pressure and NPSP at start.
17	Qual Test #15	450	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 −0	38.5±.5	41.0±1	175.0±2	Start with max helium supply press (500-525 psia), P.U. excursion with tank press. flow at min. and max. M.R.
18	Qual Test #16	150	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	Nominal condition - repeat conditions not met in previous test.
19	Qual Test #17	150	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	Nominal condition - repeat conditions not met in previous test.
20	Qual Test #18	150	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	Nominal condition - repeat conditions not met in previous test.
21	Qual Test #19	150	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	Nominal condition - repeat conditions not met in previous test.

* Mylar Blanket Required
A/R - As Required
△ - Rapid Relight

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TABLE I

QUALIFICATION TEST PROGRAM

Test No.	Test Type	Planned Duration (Secs.)	FPIP	Start Inlets FPIT	Start Inlets OPIP	OPIT	Prestart (Sec) Fuel	Prestart (Sec) LOX	FPIP	Steady State Inlets FPIT	Steady State Inlets OPIP	OPIT	Remarks
22	Qual Test #20	450	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	Nominal condition - repeat conditions not met in previous test.
23	Final Calibration	450	27.5±.5	38.5±.5	44.0±2	176.0±2	40	220	25.0+1 -0	38.5±.5	41.0±1	175.0±2	Final calibration with P.U. excursion to determine performance degradation.

A/R - As Required

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SECTION V
ENGINE ENDURANCE TEST

A. METHOD OF TEST

RL10A-3-3B engine XR103-2 was mounted in E-6 test stand and instrumented in accordance with the production RL10A-3-3B Test Instruction Sheet (TIS). Additional instrumentation required for the qualification program is shown in Table V-1. All automatic aborts were used in accordance with the TIS and additional aborts shown in Table V-2 were also used.

Table V-1. *Additional Instrumentation for Qualification Testing*

Nomenclature	*Header*	*Range*
Oxidizer Flowmeter Pressure	OP-P11	0-100 psia
Turbine Discharge Pressure	TD-P11	0-1000 psia
Turbine Discharge Temperature	TD-T1R	200-550°R
Heat Exchanger Gas Inlet Pressure	HXGIP1	0-15 psia
Mae West Skin Temperature No. 1	MWST1A	40-700°R
Mae West Skin Temperature No. 2	MWST2A	40-700°R
Mae West Skin Temperature No. 3	MWST3A	40-700°R
Fuel Pre-start Solenoid Coil Temperature	PSCT1A	40-1200°R
Oxidizer Pre-start Solenoid Coil Temperature	PLCT1A	40-1200°R
Fuel Pump Interstage Valve Position	S10PP1	Open/Close
Fuel Pump Discharge Valve Position	SV6PP1	Open/Close

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Table V-2. *Additional Automatic Aborts for Qualification Testing*

- Low-low Chamber Pressure Abort
  1. Sample Time — From +0.470 - 0 sec until +0.490 + 0 sec
  2. Pressure Switch Level — 8 ± 0.5 psia (measure at igniter tap)
- Diffuser Downstream Pressure Abort
  1. Sample Time — From 3 ± 1 sec prior to start until shutdown
  2. Abort Level — If HXG1P1 exceeds 10 psia run shall be aborted.
- Oxidizer Pump Discharge Pressure Abort
  1. Sample Time — From + 2.7 sec until 0.1 sec prior to shutdown.
  2. Abort Level — If OPDP11 is less than 120 psia the run shall be aborted.
  3. Interlock — If OPDP11 is less than 120 psia when FVUP11 reaches 400 psia the run shall be aborted.
     — Interlock to be on from 1 sec prior to start until 0.1 sec prior to shutdown.

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All test firings were performed in test stand E-6. The engine was mounted in a vertical attitude and enclosed in an altitude chamber that was connected to the test stand exhaust diffuser system. A steam ejector system was used to evacuate the altitude chamber and the engine exhaust system prior to engine start and to maintain simulated space conditions during steady-state operation and shutdown.

The engine was attached to a mounting plate that was supported by three axially oriented rods equipped with axial load cells for measuring engine thrust. The engine gimbal fixed rods, which replace the vehicle gimballing actuators, also attach to this mounting plate. Propellants were supplied to the engine pump inlets from gas-pressurized, vacuum-jacketed test stand storage tanks mounted above the engine via vacuum-jacketed, gimbal-flexed propellant lines.

Each of the propellant flows was measured by two flowmeters installed in series in the supply line. Figures V-1 and V-2 show the engine mounted in the test stand. Figure V-3 shows the test stand schematic. The test configuration is essentially the same as that used for prior qualification tests and for production acceptance test.

Minimum chamber temperature conditions were obtained by running a rapid relight test instead of precooling the thrust chamber to a specified "cold jacket" temperature. The rapid relight more closely simulates actual conditions which occur during engine operation in space.

Cold solenoid coil conditioning was accomplished by passing cold hydrogen through copper coils around each solenoid coil. Heated chamber conditioning was accomplished by passing ambient hydrogen through a heater prior to introduction to the chamber. Solenoid heating was accomplished by passing steam through the coils around the solenoids. The schematic for these systems is shown in Figure V-4.

The General Dynamics thermal insulation blanket was installed on the engine for all rapid relight runs. A typical blanket installation is shown in Figure V-5. A nitrogen purge was supplied under the blanket and was actuated at 10 seconds prior to start. This purge was used to provide an inert atmosphere under the blanket to prevent the possibility of fire damage to the blanket should there be any hydrogen leaks.

The engine solenoids and ignition system were supplied with a nominal 28 volts dc and a nominal helium pressure of 470 psia was supplied to the engine except when these inputs were varied in accordance with specific test requirements.

Automatic data recording equipment was used to record engine transient and steady-state performance. All instrumentation was maintained within the calibration requirements of current P&W Instrumentation Procedures. The thrust measuring system was routinely recalibrated during the test program. All calibrations are traceable to the National Bureau of Standards.

Static leakage tests of the fuel, oxidizer, and helium systems were conducted before and after the endurance testing in accordance with the end item test procedure.

B. TESTING AND RESULTS

1. Engine Tests

Engine XR103-1 was mounted in the E-6 test stand on 4 December 1985. Testing began on 5 December 1985. Hot Run (HR) 01.01 was a trim run per the RL10A-3-3B TIS. Due to pump vibration problems and silver throat washout, the engine was removed from the test stand on 6 December 1985 and returned to the RL10 assembly floor. Photos of the silver throat were taken prior to test; see Figures V-6 through 10. Photos showing silver throat washout were taken after test, Figures V-11 and 12.

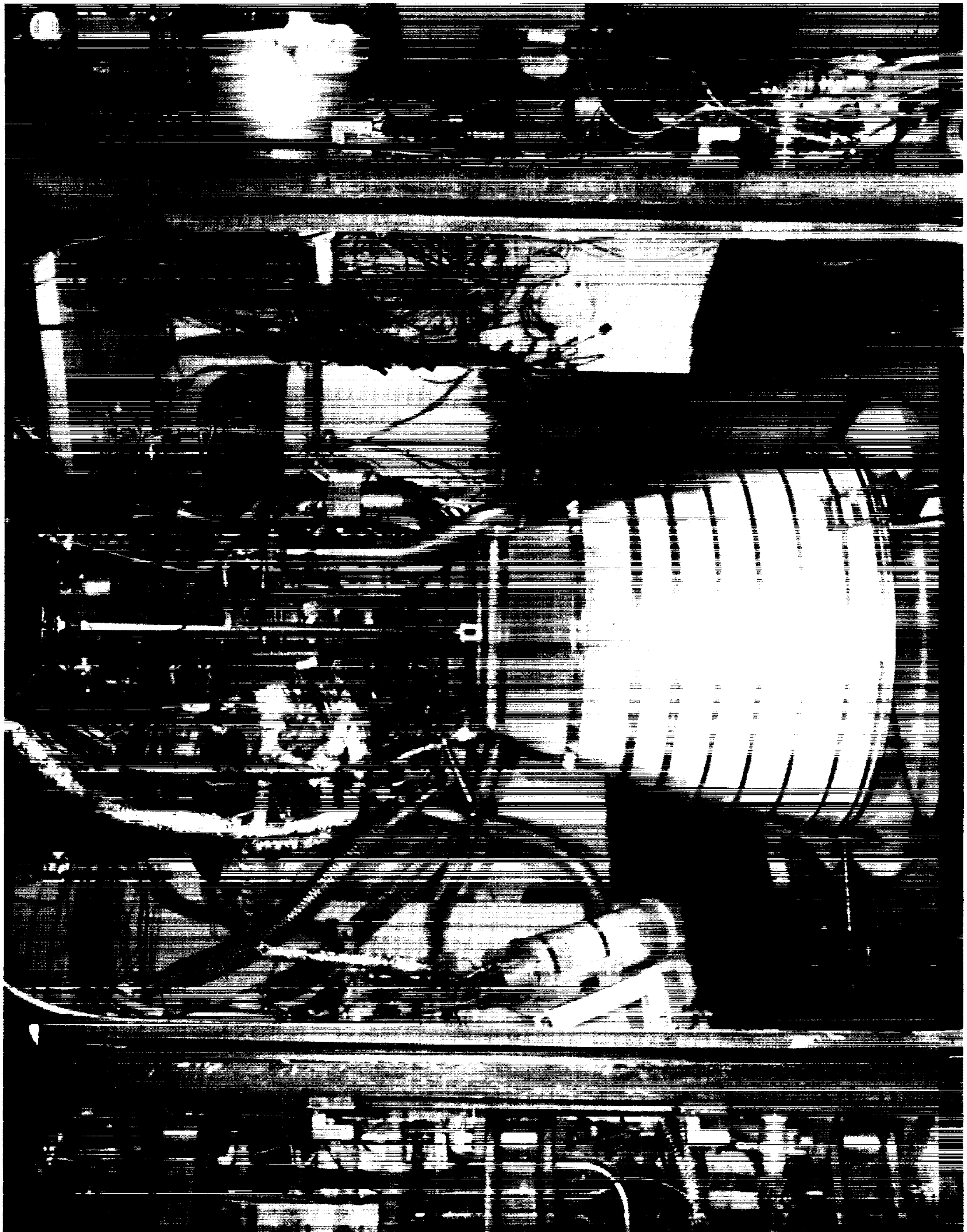

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Figure V-1. RL10A-3-3B Engine Mounted in the Test Stand

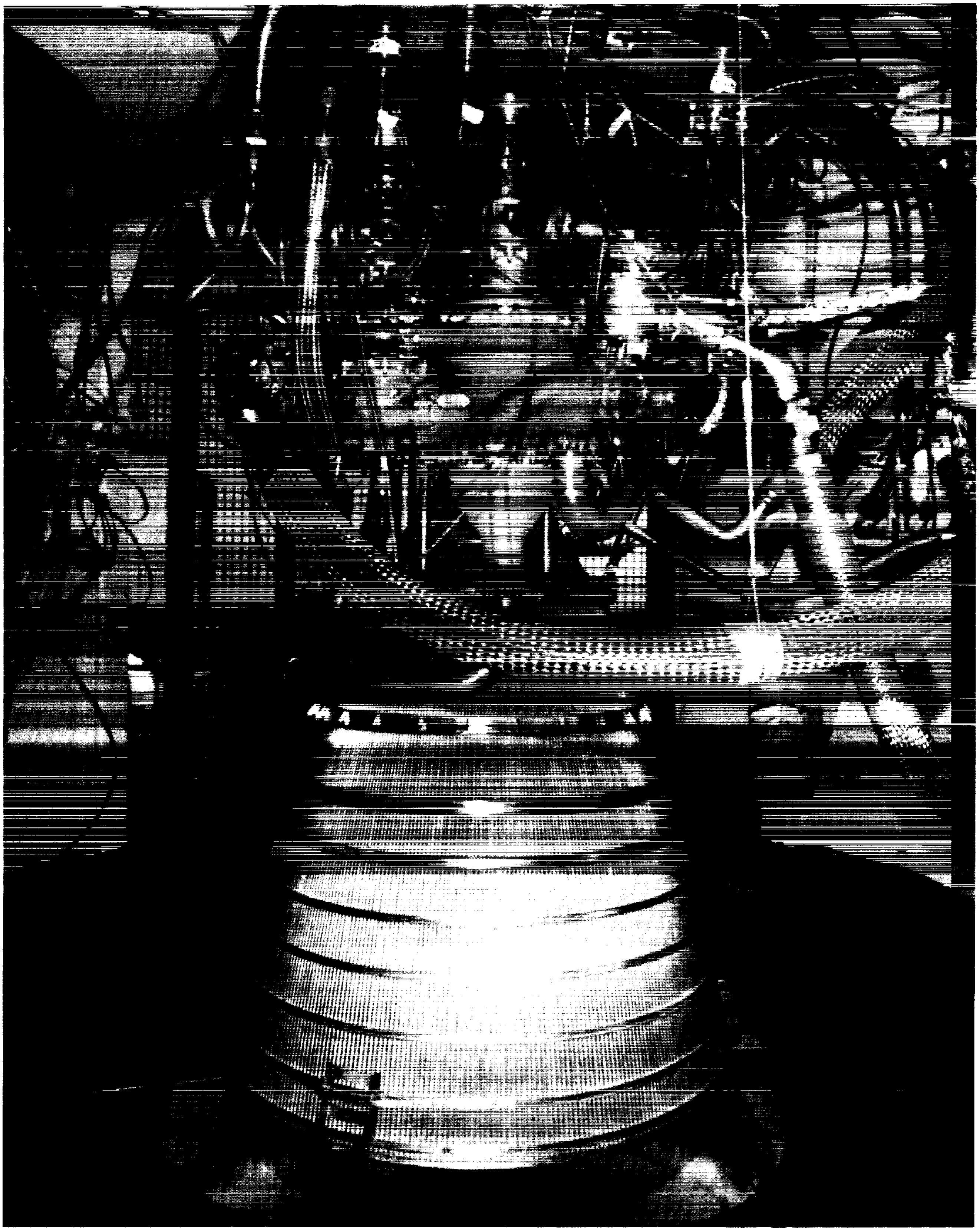

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Figure V-2. RL10A-3-3B Engine Mounted in the Test Stand

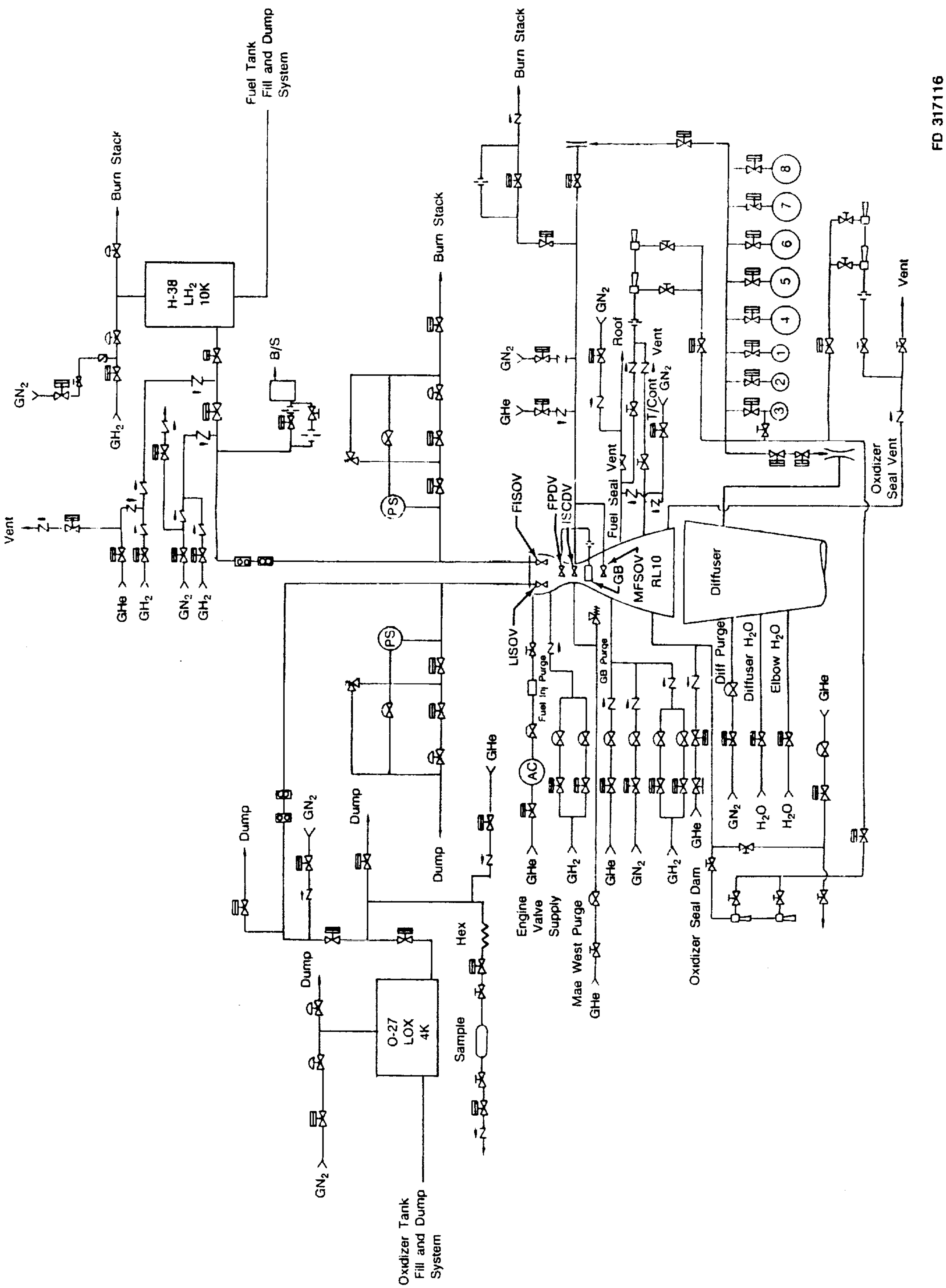

Figure V-3. Simplified Test Stand Schematic

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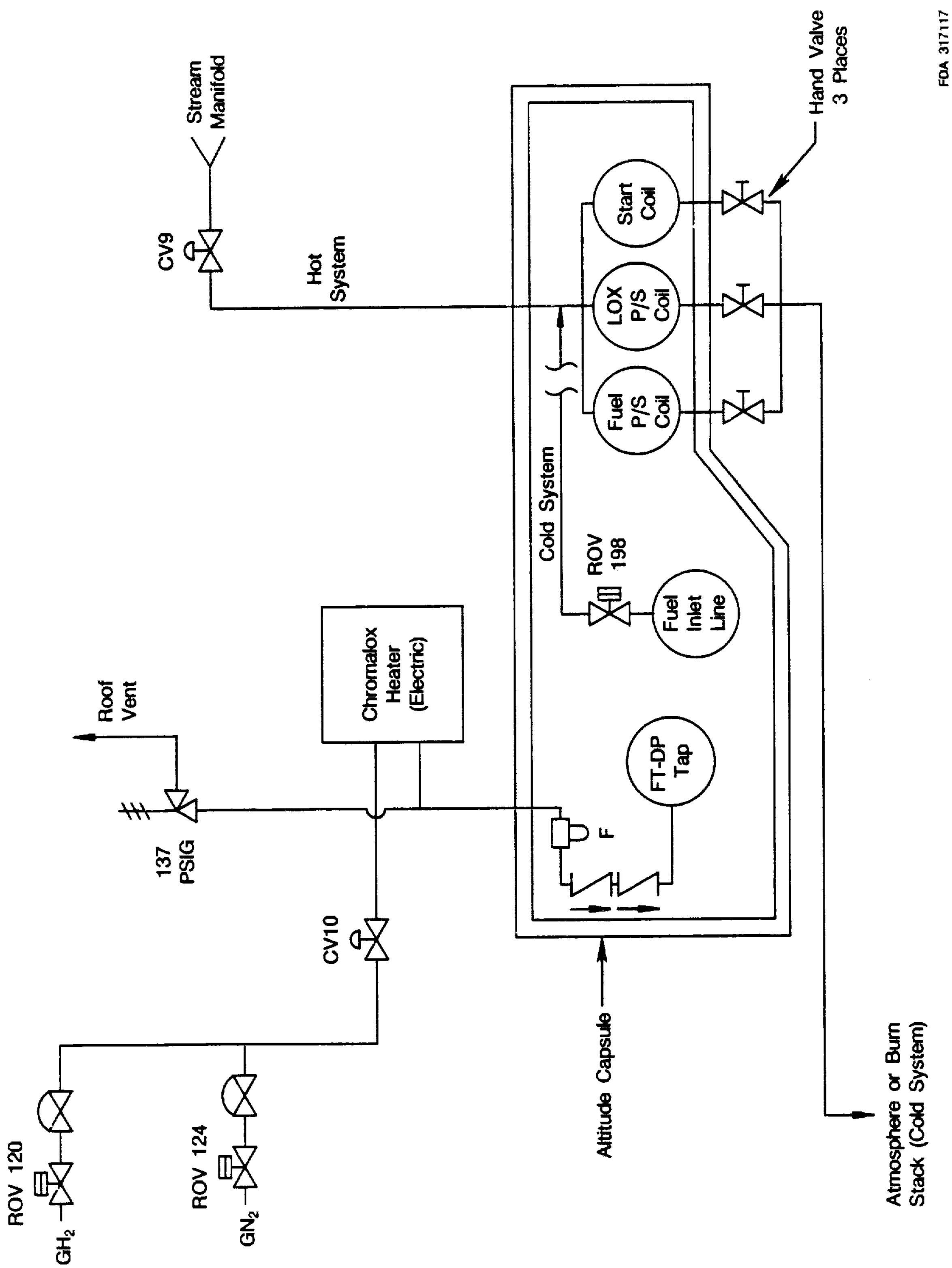

Figure V-4. Hot Chamber and Hot/Cold Solenoid Schematic

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Figure V-5. Thermal Insulation Blanket Installed on Engine

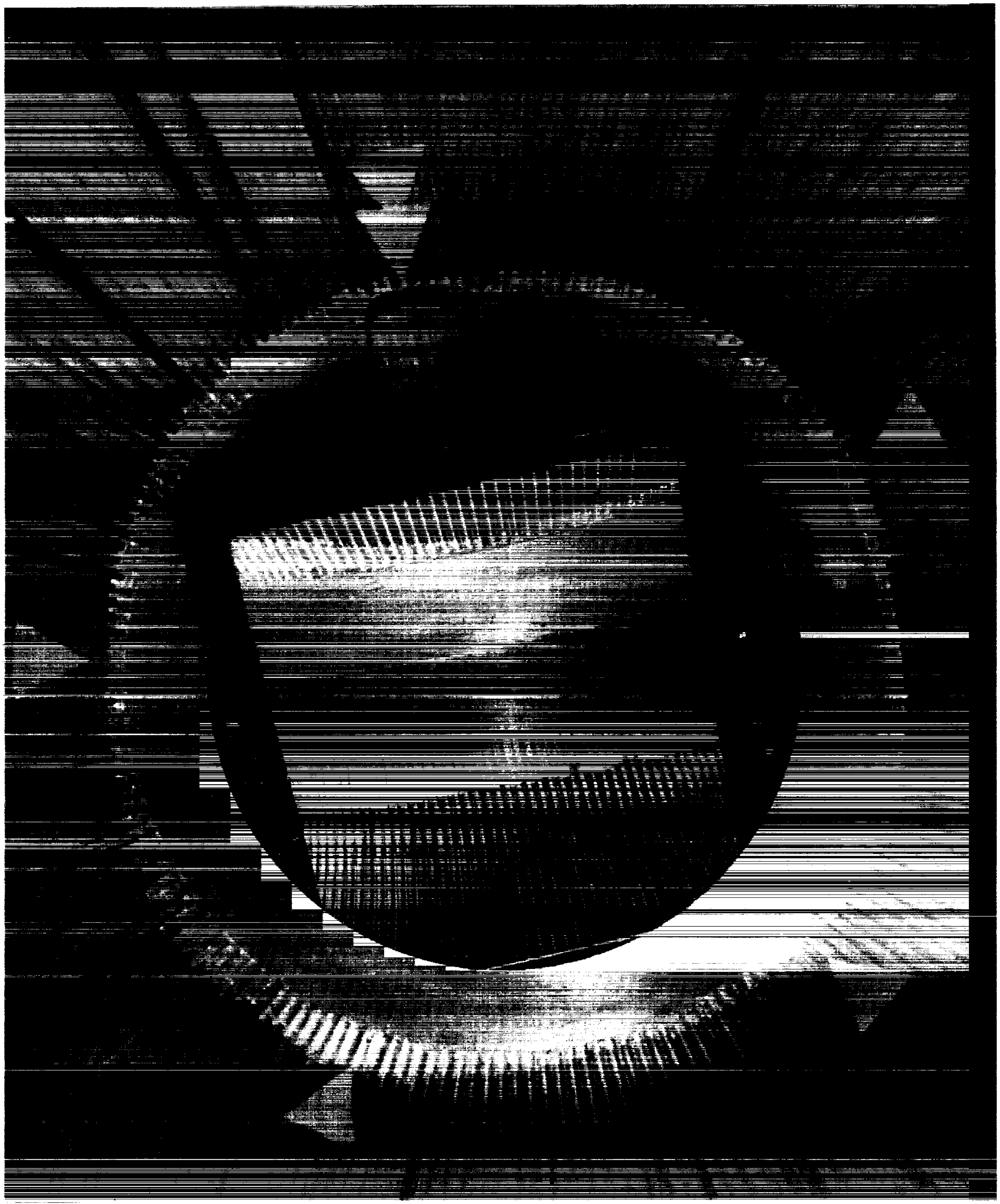

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Figure V-6. RL10A-3-3B Silver Throat — Before Test

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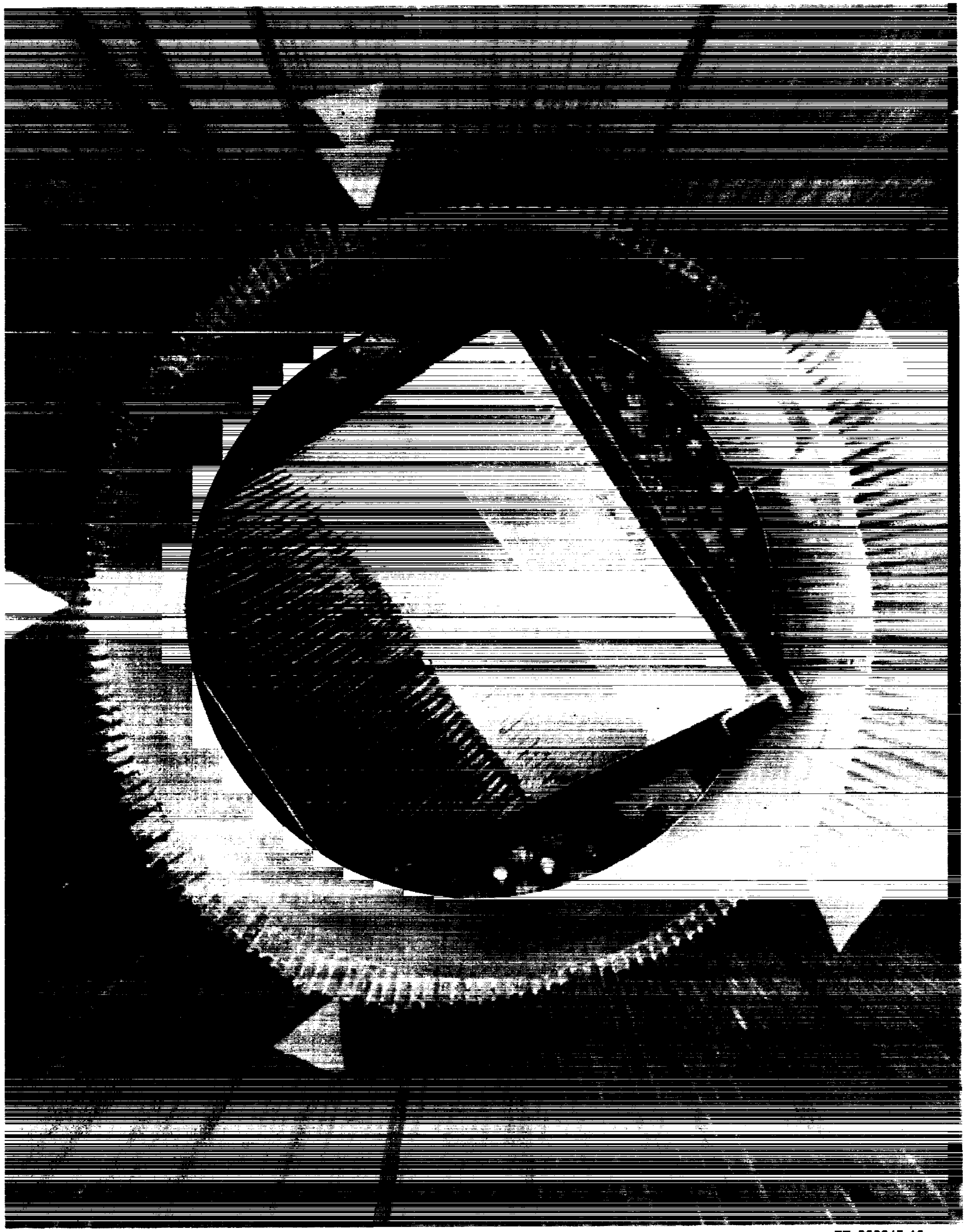

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Figure V-7. RL10A-3-3B Silver Throat — Before Test

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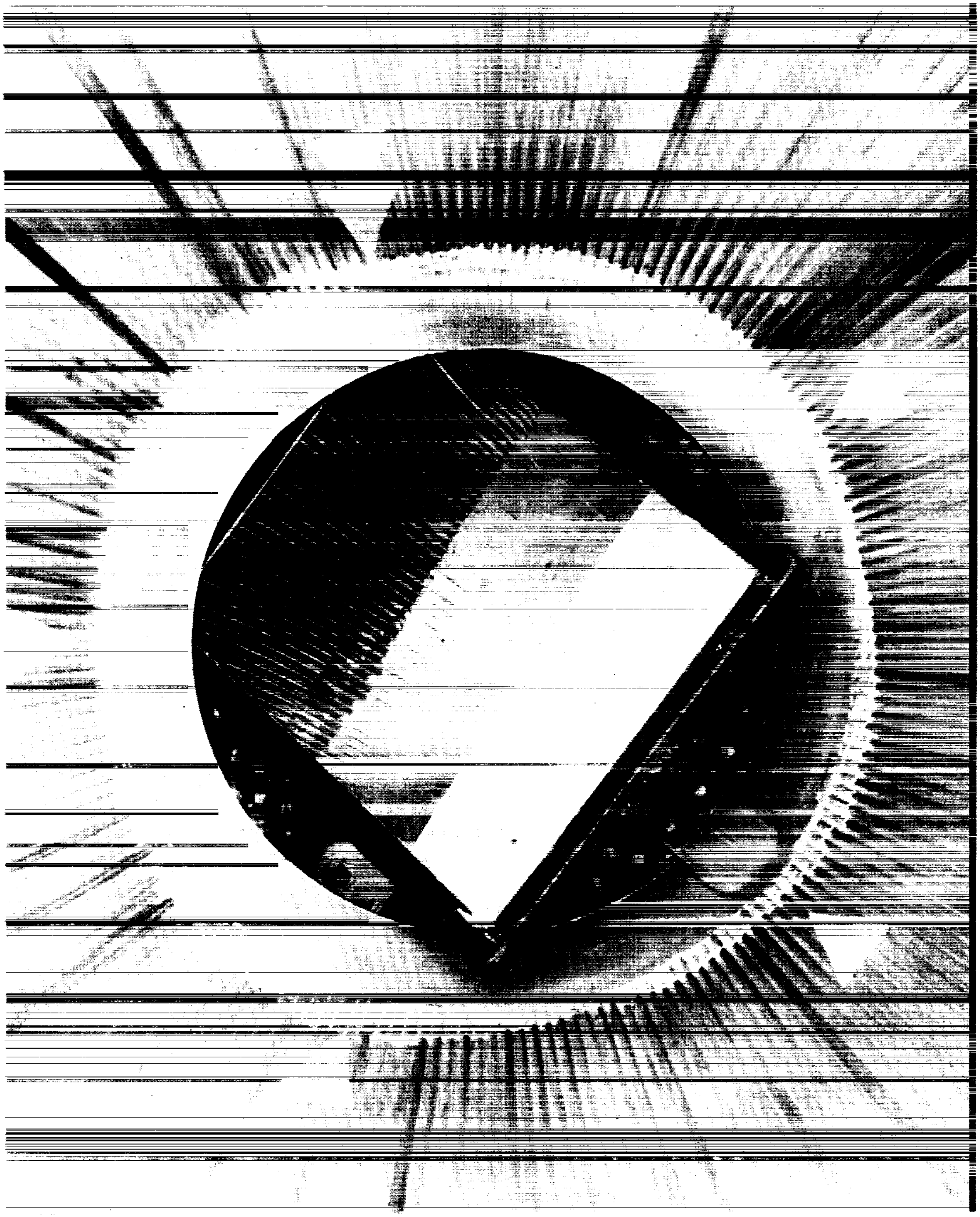

Figure V-8. RL10A-3-3B Silver Throat — Before Test

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Figure V-9. RL10A-3-3B Silver Throat — Before Test

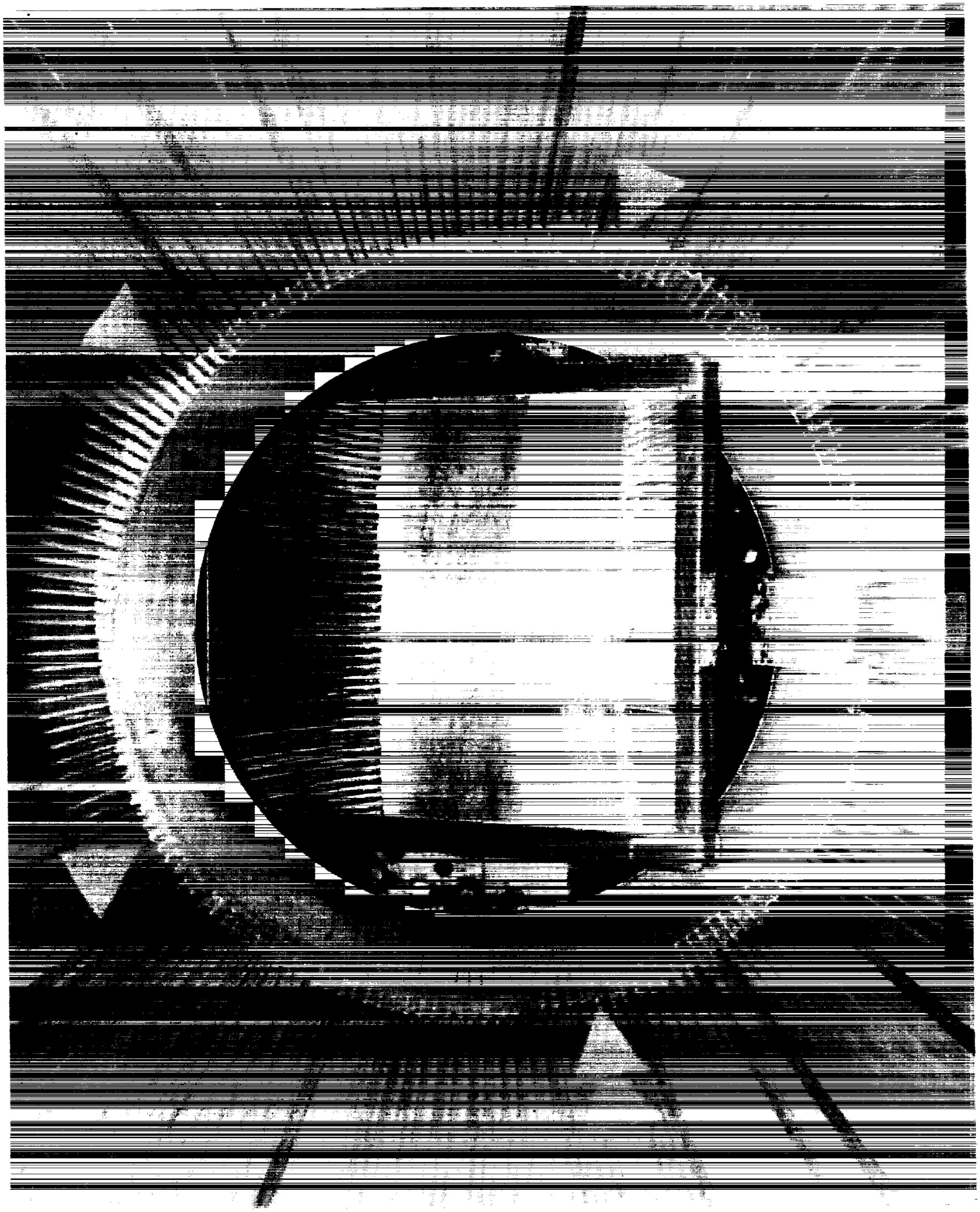

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Figure V-10. RL10A-3-3B Silver Throat — Before Test

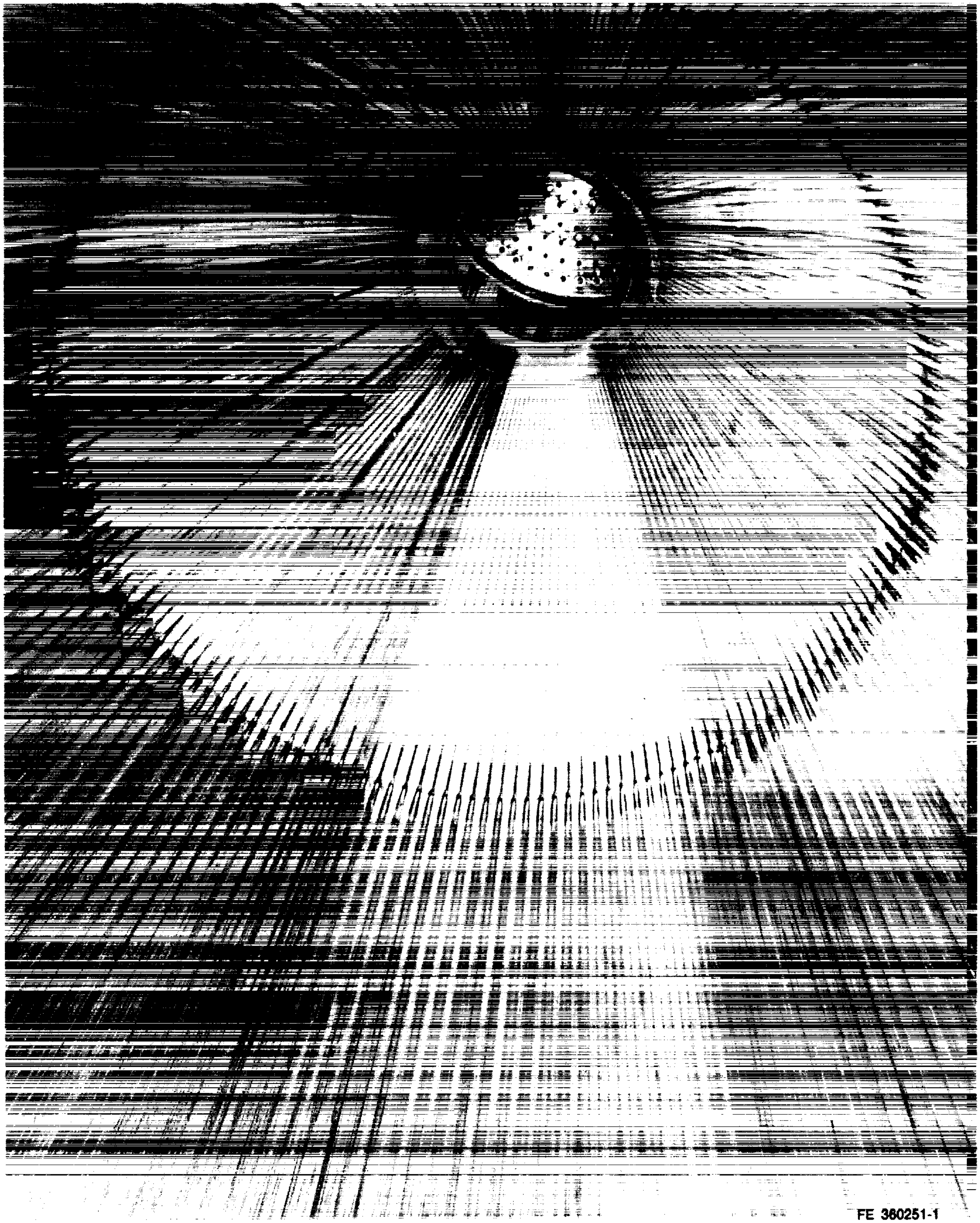

Figure V-11. RL10A-3-3B Silver Throat Washout — After Test

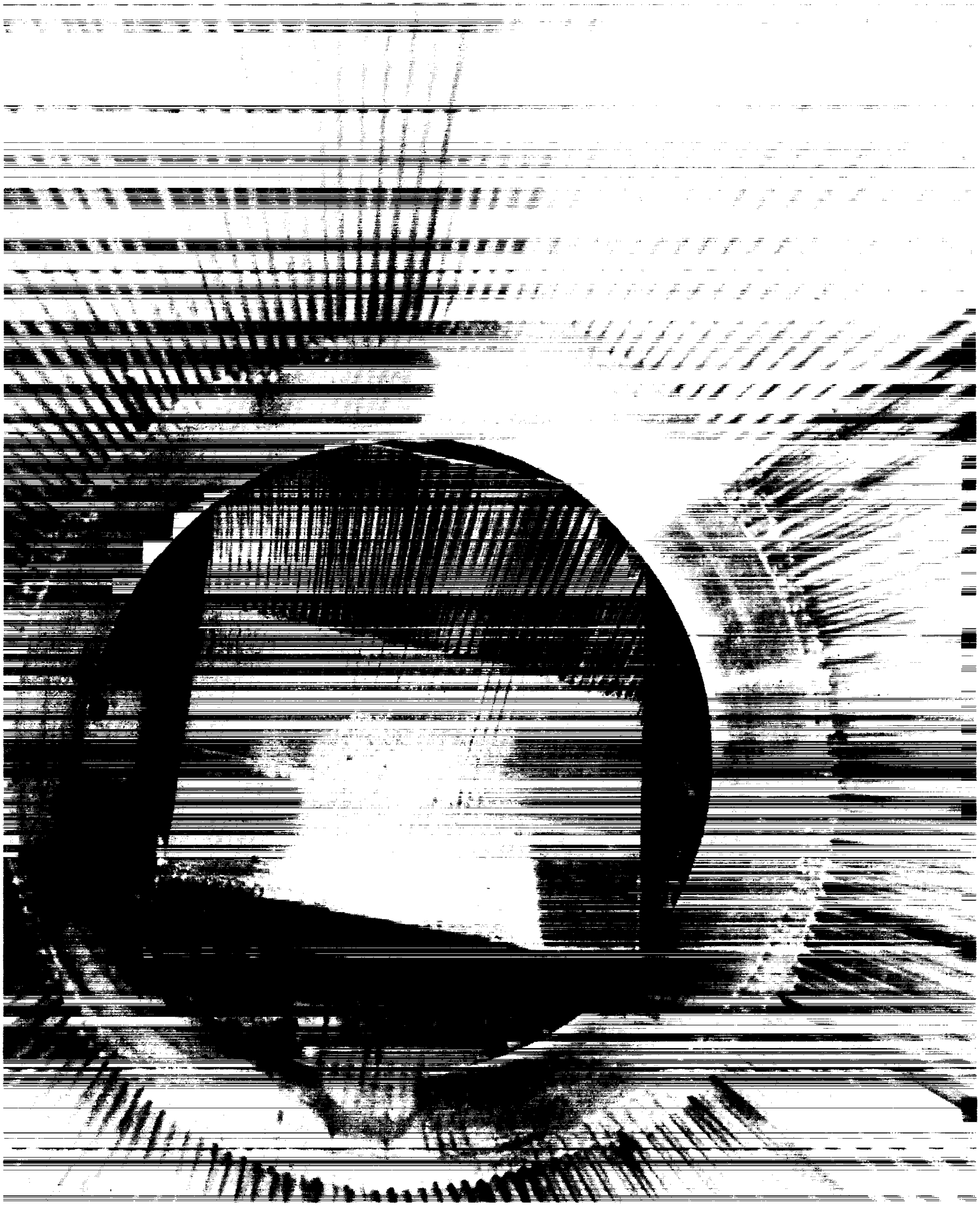

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Figure V-12. RL10A-3-3B Silver Throat Washout — After Test

The turbopump vibration and silver throat washout occurring on the initial test are problems which would be found and corrected before delivery of production engines. Therefore, they may be corrected before initiation of the qualification test.

Engine XR103-2 was mounted in the E-6 stand on 17 December 1985. Testing began on 18 December 1985. Trim and trim repeat runs were conducted per the RL10A-3-3B TIS prior to beginning the Qual Test. The Qual Test was then conducted followed by a final calibration. All testing was completed on 15 January 1986. Table V-3 shows test conditions required by the Test Plan and the engine run which accomplished them. Table V-4 is a summary of the test program in chronological order.

***Table V-3.** Accomplishment of Qualification Requirements*

Required No. of Firings	*Condition*	*Hot Run Number*
4	450 sec duration: engine calibration	4.01, 5.01, 24.01, 25.01
1	Minimum voltage to solenoids	4.01
1	Maximum voltage to solenoids	26.01
1	Minimum helium pressure to solenoids	24.01
1	Maximum helium pressure to solenoids	25.01
4	Minimum O/F steady-state	4.01, 5.01, 24.01, 25.01
4	Maximum O/F steady-state	4.01, 5.01, 24.01, 25.01
1	Relight after 2 minutes	22.01
1	Minimum chamber temperature	19.01
1	Minimum solenoid temperature	15.01
1	Maximum chamber/solenoid temperatures	13.01
4	First burn cooldown limits	07.01, 09.01, 11.01, 15.01
4	Relight cooldown limits	08.01, 10.01, 12.01, 16.01
1	Start at minimum FPIP and OPIP (and NPSP)	15.01
1	Start at maximum FPIP and OPIP (and NPSP)	09.01
1	Start at minimum FPIP and maximum OPIP (and NPSP)	07.01
1	Start at maximum FPIP and minimum OPIP (and NPSP)	11.01
4	Maximum tank pressurization flow at O/F extremes	4.01, 5.01, 24.01, 25.01
1	Minimum steady-state fuel NPSP	26.01
1	Minimum steady-state oxidizer NPSP	24.01
1	Shutdown from minimum O/F	24.01
1	Shutdown from maximum O/F	27.01
*	Run 200 seconds at greater than 6.7 O/F	4.01, 5.01, 24.01, 27.01

* This requirement was added by mutual agreement between NASA and Pratt & Whitney after the test plan was submitted and is not a requirement of Model Spec. 2295. Total time at a mixture ratio of 6.7 or greater is 905.9 seconds.

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Table V-4. Qual Test Engine Summary

Hot Run No.	Qual Test No.	Date	Run Time (Sec)	Objectives	Results
Build 1					
01.01		12/5/85	320.1	RL10A-3-3B trim per TIS paragraph 3.3.4	Made successful trim run. Had turbopump vibration over limit and silver throat washout.
Build 2					
02.01		12/18/85	340.1	RL10A-3-3B trim per TIS paragraph 3.3.4	Made successful trim run — met all run objectives.
03.01		12/19/85	451.2	RL10A-3-3B trim repeat run per TIS paragraph 5.2.2.3. Run a 7 point P.U. excursion from 5.2 to 6.75 M.R. GMRV preset increased 2 turns to allow M.R. to get to 6.75, tank pressurization flow demonstration per TIS paragraph 5.2.2.4	Made successful trim repeat run with P.U. excursion. Set mixture ratio directly using trim computer output instead of setting P.U. angle. Had a flash fire at shutdown at interface between pump discharge cooldown valve and stand dump line. Retorqued flange bolts before next run. LOX inlet valve actuation time was too fast and inspection of the helium port showed no orifice was installed. A B/M 0.060 in. dia. orifice was installed.
				Start of Qualification Test	
04.01	1	12/20/85	451.0	Qual test number 1 — start with minimum solenoid/igniter voltage. Make 450 second calibration run with min of 200 secs at >6.7 M.R. Make tank pressurization flow. Shutdown at min. M.R.	Made successful start and run. Ran with stand fuel dump valve open but data later indicated mixture ratio requirements were met. Installed mylar blanket after run.
05.01	5	12/20/85	451.1	Repeat Qual Test No. 1 — due to open dump valve it was believed mixture ratio requirements for Test No. 1 had not been met. Min. igniter/solenoid voltage was completed on H.R. 04.01 and did not require repeating.	Made successful start and run. Since post-test data analysis for H.R. 4.01 indicated mixture ratio requirements had been met, run 5.01 was used as Qual Test No. 5. Max voltage to solenoids/igniter, shutdown at max M.R. and min. steady state full NPSP demonstration will be made up on a later run.
06.01	16	12/23/85	150.0	1st burn cooldown limits per Qual test No. 8 followed by rapid relight per Qual Test No. 9	Made successful start and run but the abort system was not set up correctly for a relight and the run was aborted during the shutdown transient. Run was used as Qual Test No. 16.
07.01	11	1/3/86	150.0	1st burn cooldown limits per Qual Test No. 11. Min fuel and max oxidizer pressure and NPSP start.	Made successful start and run.
08.01	12	1/3/86	151.1	Relight cooldown limits per Qual Test No. 12. Same inlet conditions as H.R. 07.01	Made successful relight and run.
09.01	8	1/3/86	150.0	1st burn cooldown limits per Qual Test No. 8. Max fuel pressure and NPSP at that pressure and max. oxidizer pressure and NPSP at start.	Made successful start and run.

Table V-4. *Qual Test Engine Summary (Continued)*

Hot Run No.	Qual Test No.	Date	Run Time (Sec)	Objectives	Results
10.01	9	1/3/86	151.1	Relight cooldown limits per Qual Test No. 9. Same inlet conditions as H.R. 09.01	Made successful relight and run.
11.01	13	1/3/86	150.0	1st burn cooldown limits per Qual Test No. 13. Max fuel pressure and NPSP at that pressure and min oxidizer pressure and NPSP at start.	Made successful start and run.
12.01	14	1/3/86	151.0	Relight cooldown limits per Qual Test No. 14. Same inlet conditions as H.R. 11.01	Made successful relight and run.
13.01	3	1/8/86	100.0	Preheat thrust chamber and solenoids per Qual Test No. 3	Made successful start and run.
14.01	—	1/8/86	0	Relight 2 minutes after shutdown of previous run per Qual Test No. 4	Relight run was aborted by lo-lo chamber pressure abort - engine did not light within allowable time limits.
15.01	6	1/9/86	150.0	1st burn cooldown limits with min fuel and min. oxidizer pressure and NPSP at start and precooled solenoids per Qual Test No. 6	Made successful start and run.
16.01	7	1/9/86	120.0	Relight cooldown limits per Qual Test No. 7	Made successful relight and run.
17.01	—	1/9/86	6.0	Added 5 second run to investigate 2nd burn no lights	Made successful start and run.
18.01	17	1/10/86	150.0	Nominal condition per Qual Test No. 17	Made successful start and run.
19.01	2	1/10/86	150.0	Relight 30 secs. after shutdown of previous run. Minimum chamber temperature per Qual Test No. 2	Made successful relight and run.
20.01	—	1/10/86	6.2	Added 5 second run to investigate 2nd burn no lights	Made successful relight and run
21.01	18	1/10/86	60.0	Nominal condition per Qual Test No. 18	Made successful start and run
22.01	4	1/10/86	60.0	Relight 2 minutes after shutdown of previous run per Qual Test No. 4	Made successful relight and run. LOX cooldown was extended to 10 seconds as opposed to 5 seconds used on H.R. 14.01
23.01	—	1/10/86	6.2	Added 5 second run to investigate 2nd burn no lites	Made successful relight and run.
24.01	10	1/13/86	510.1	Start with minimum helium supply pressure. Make 450 sec. calibration run with min 200 secs at > 6.7 M.R. Perform min steady state oxidizer NPSP demo and make tank pressurization flows at min and max M.R. per Qual Test No. 10.	Made successful start and run. Met all run objectives

Table V-4. Qual Test Engine Summary (Continued)

Hot Run No.	Qual Test No.	Date	Run Time (Sec)	Objectives	Results
25.01	15	1/14/86	450.9	Start with maximum helium supply pressure. Make 450 sec calibration run with min 200 secs at > 6.7 M.R. Make tank pressurization flows at min and max. M.R. per Qual Test No. 15	Made successful start and run. Met all run objectives.
26.01	19	1/14/86	350.8	Start with maximum voltage to igniter and solenoids. Perform min steady state fuel NPSP demo per Qual Test No. 19	Made successful start and run. Met all run objectives. Had vibration spike at start but dropped to normal at 25 secs into the run.
27.01	20	1/15/86	476.5	Make 450 second calibration run with min. 200 secs. at > 6.7 M.R. Shutdown at max M.R. per Qual Test No. 20	Made successful start and run. Met all run objectives. Vibration (1E) hit 6g's but dropped within limits in less than 20 secs.
28.01	—	1/15/86	350.1	Make final calibration with P.U. excursion to check engine performance degradation	Made successful test and run. Met all run objectives. Had vibration spike at start. Vibration (1E) hit 6g's after start but dropped within limits in less than 20 seconds.

TOTALS

	XR103-1	XR103-2	
Total Engine Run Time	320.1	5693.4	Sec
Total Qual Test Time	0	4533.6	Sec
Total Engine Runs	1	26	
Total Qual Test Runs	0	20	
Total Time at > 6.7 M.R.	0	905.9	Sec

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2. Failure/Malfunction Reports (FMR)

Three FMRs were written during the testing of XR103-1 and XR103-2. FMR R0074 was written against the chamber/injector P/N 2180696, S/N ACB872 which suffered a severe washout of the silver throat on HR 01.01. The analysis indicated a poor bond is the reason for this occurrence. The chamber would have to be cut up to verify the lack of bond. Since the silver throat can be removed and a new one cast, the chamber was not cut up to verify the lack of bond. A test firing will assure the new silver throat is acceptable.

FMR R0075 was written against the turbopump. During HR 01.01 pump vibrations exceeded the TIS limits. The pump was rebuilt for Build 2 and the fuel pump shaft was replaced for exceeding the concentricity requirements of the drawing. Turbopump vibrations were within limits when the engine was first fired on the rebuild.

FMR R0076 was written against the no-light on HR 14.01. During the course of the Qual Test run program, two additional runs were added and oxidizer cooldown times were varied on other runs in an attempt to understand the no-light situation. It was concluded that a separate ignition program would have to be conducted. On that basis the RL10A-3-3B Qual Test program was completed to demonstrate the performance and durability of the engine while operating at increased mixture ratio. Engine ignition problems will be investigated separately, Reference P&W FR-19478, and modifications to the engine, if any, will be qualified on other test engines.

3. Diagnostic Plots

Efforts have been underway at Pratt & Whitney to develop a diagnostic system to determine immediately after an engine run if the engine is ready and capable for its next firing. Several parameters have been chosen to be plotted by computer for comparison with expected operational limits. Any actual data lying outside the set limits would require investigation prior to continuing a test program. In its final operational form such a system would be used to determine if an operational engine was ready for its next mission. Examples of these plots are provided in Figures V-13 through V-19. While the use of the diagnostic system is not a requirement of the Qualification Test Plan this section is included since the system was first used during this test program. An explanation of the plots follows:

As part of the rocket diagnostic system development, confidence bands of several parameters defining normal operation were established for both the RL10A-3-3A and RL10A-3-3B rocket engines. These bands were defined from existing engine data from nominal runs.

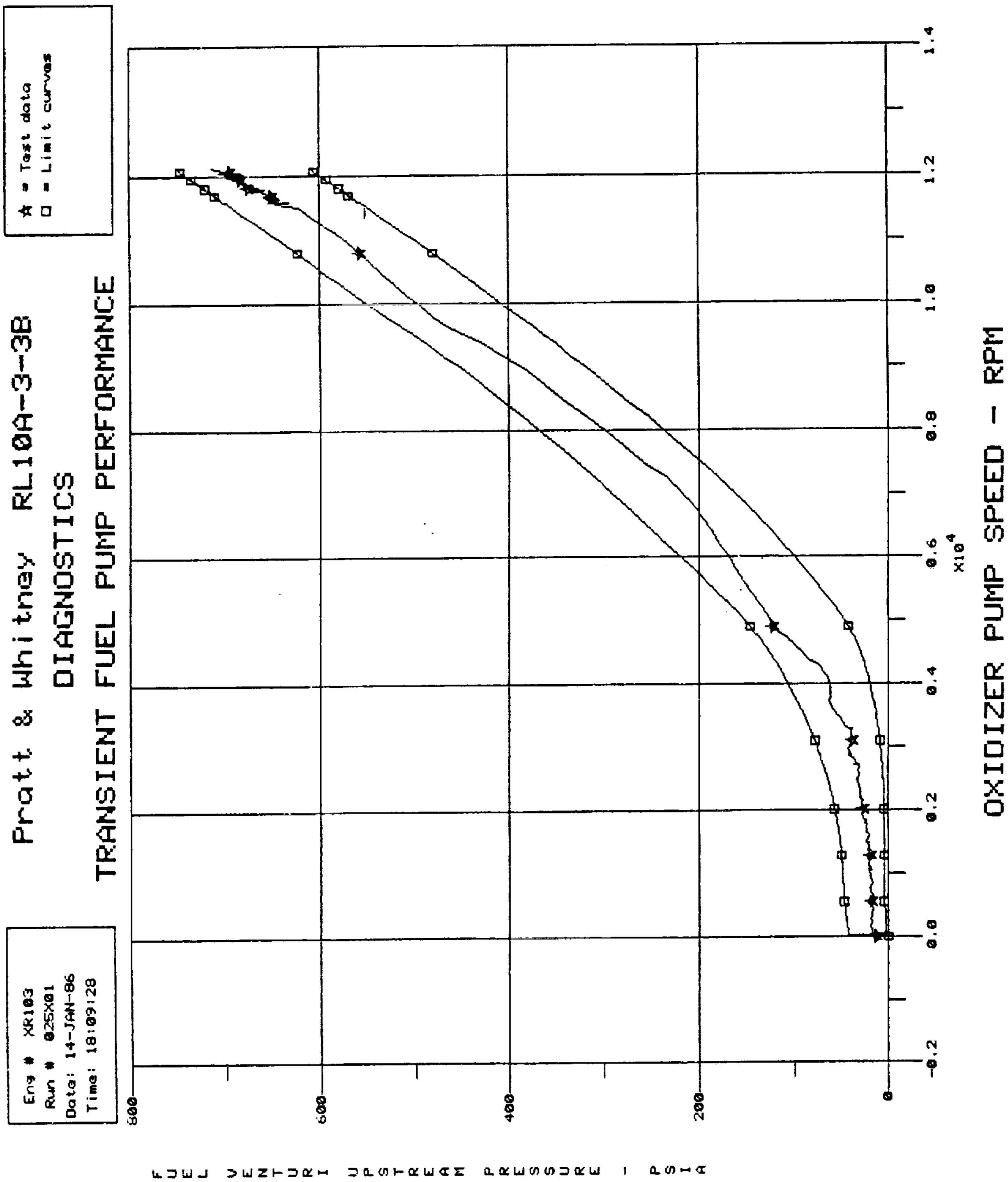

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Figure V-13. Transient Fuel Pump Performance

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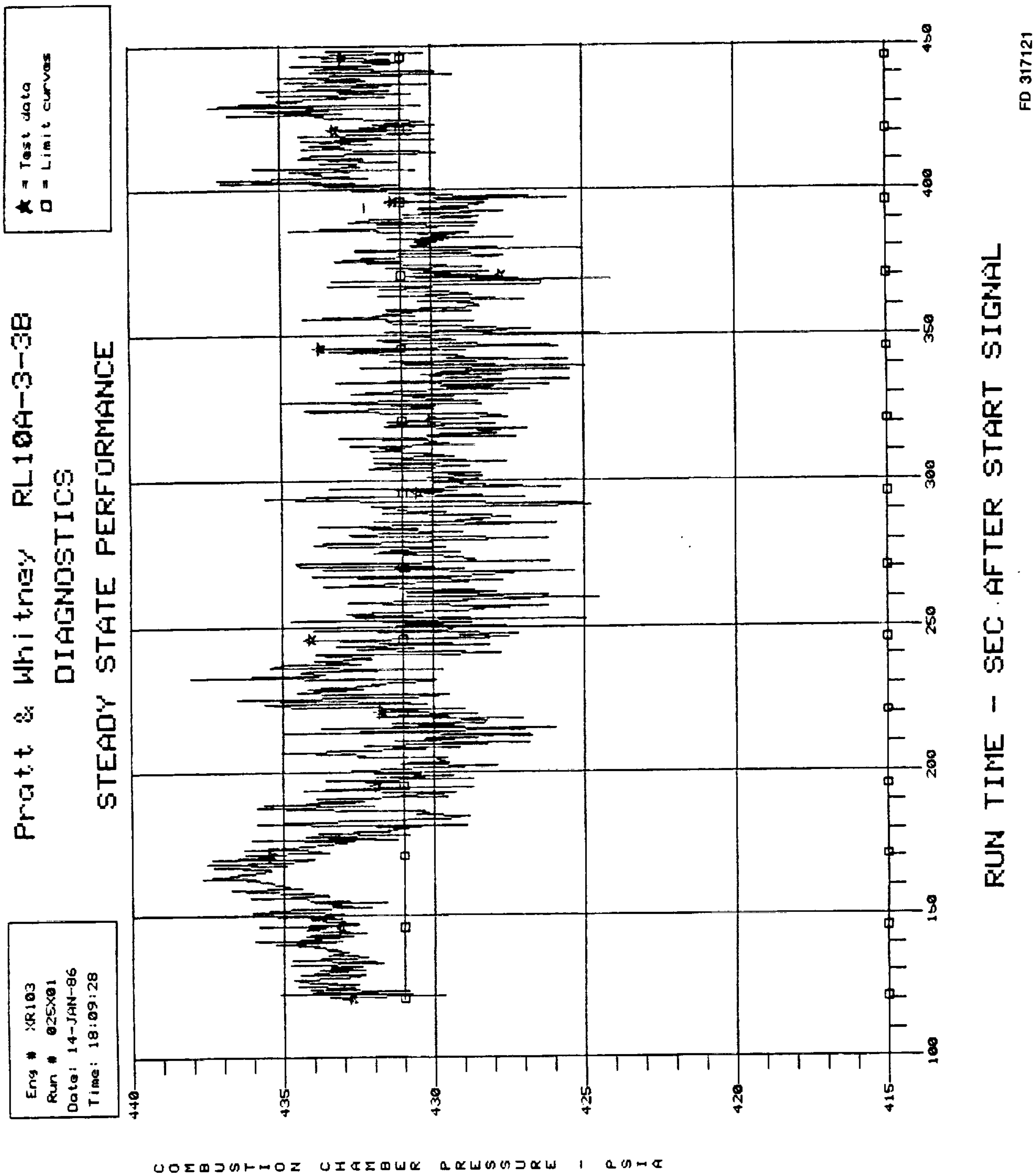

Figure V-14. Steady-State Performance

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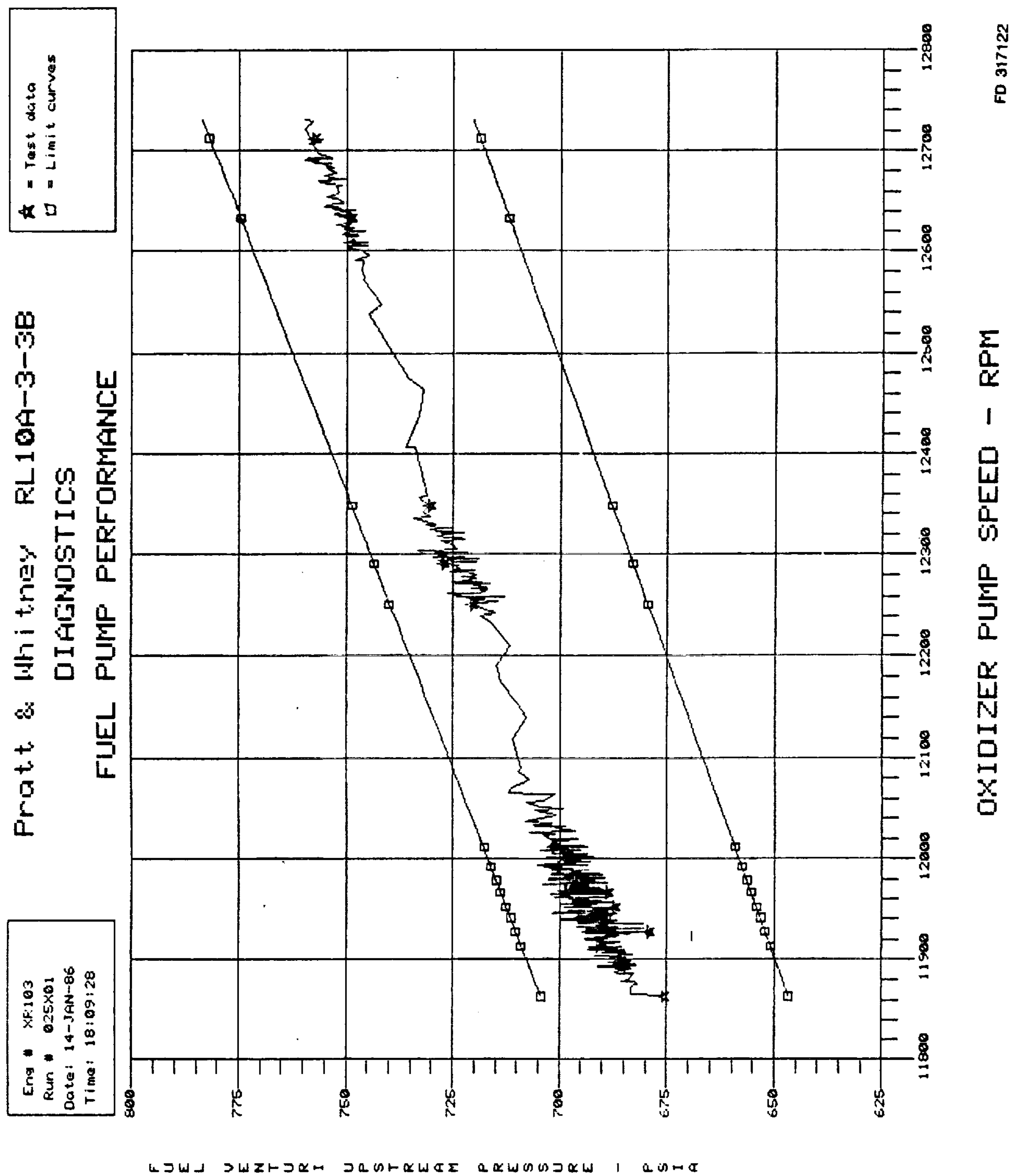

Figure V-15. Fuel Pump Performance

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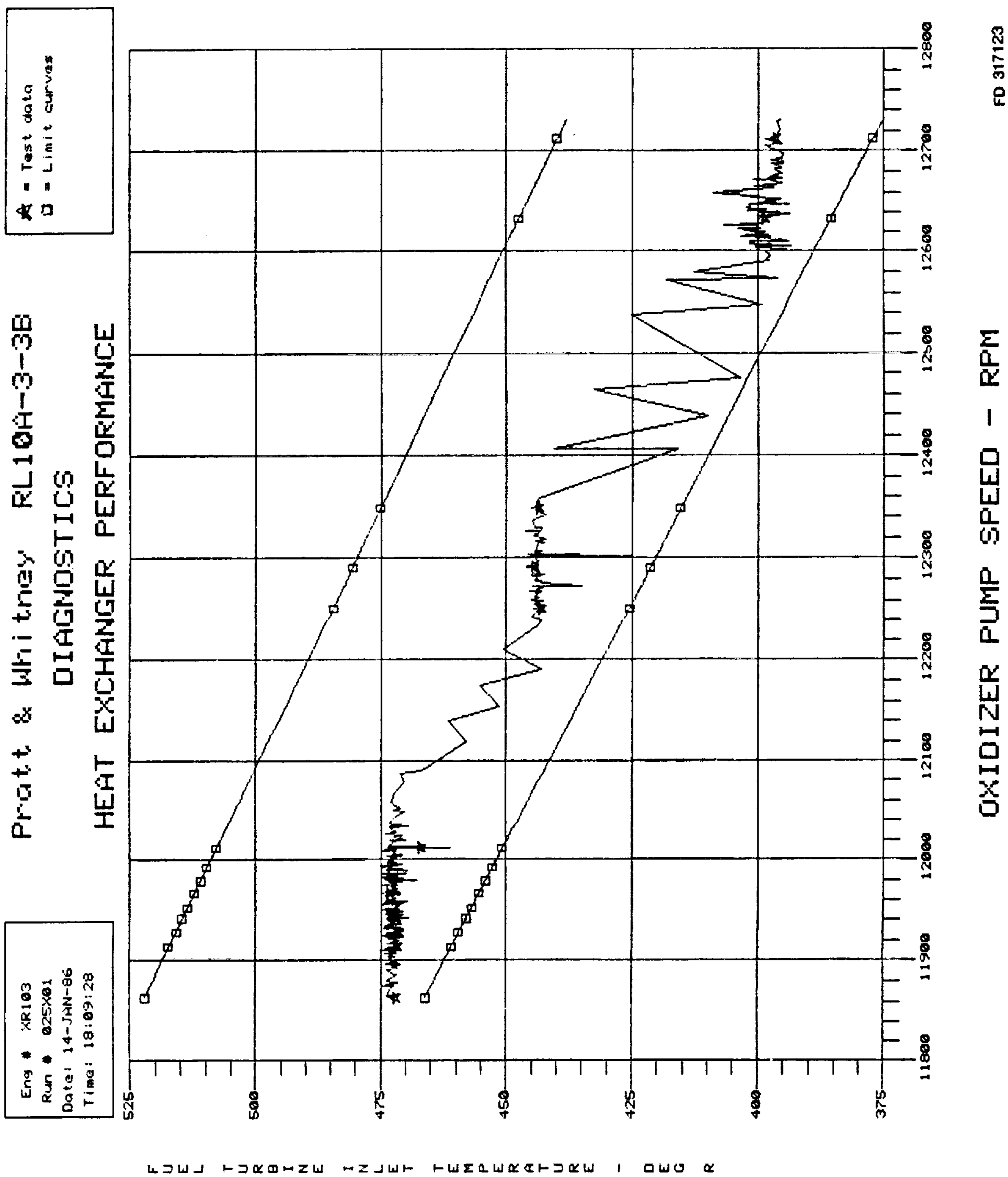

Figure V-16. Heat Exchanger Performance

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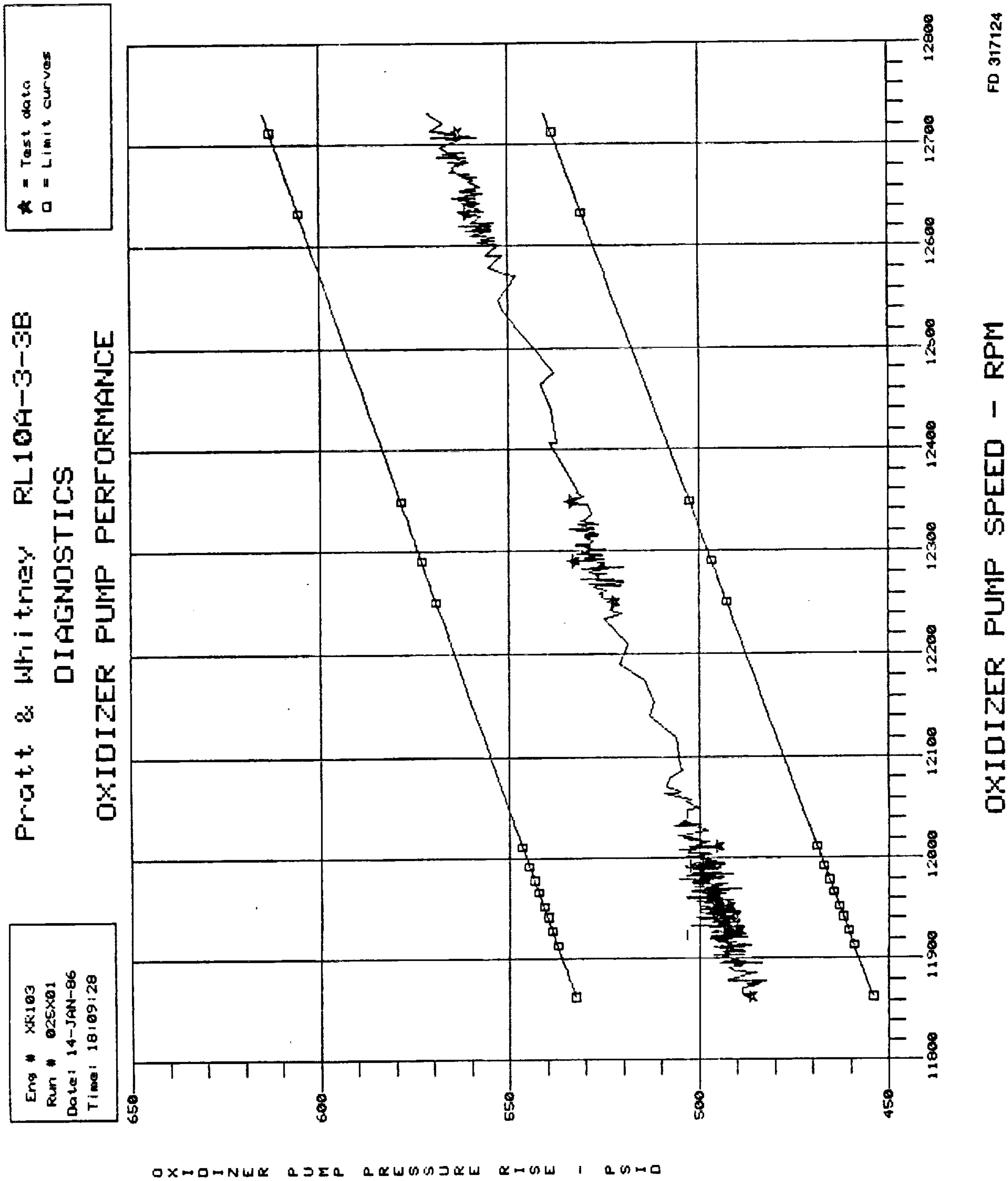

Figure V-17. Oxidizer Pump Performance

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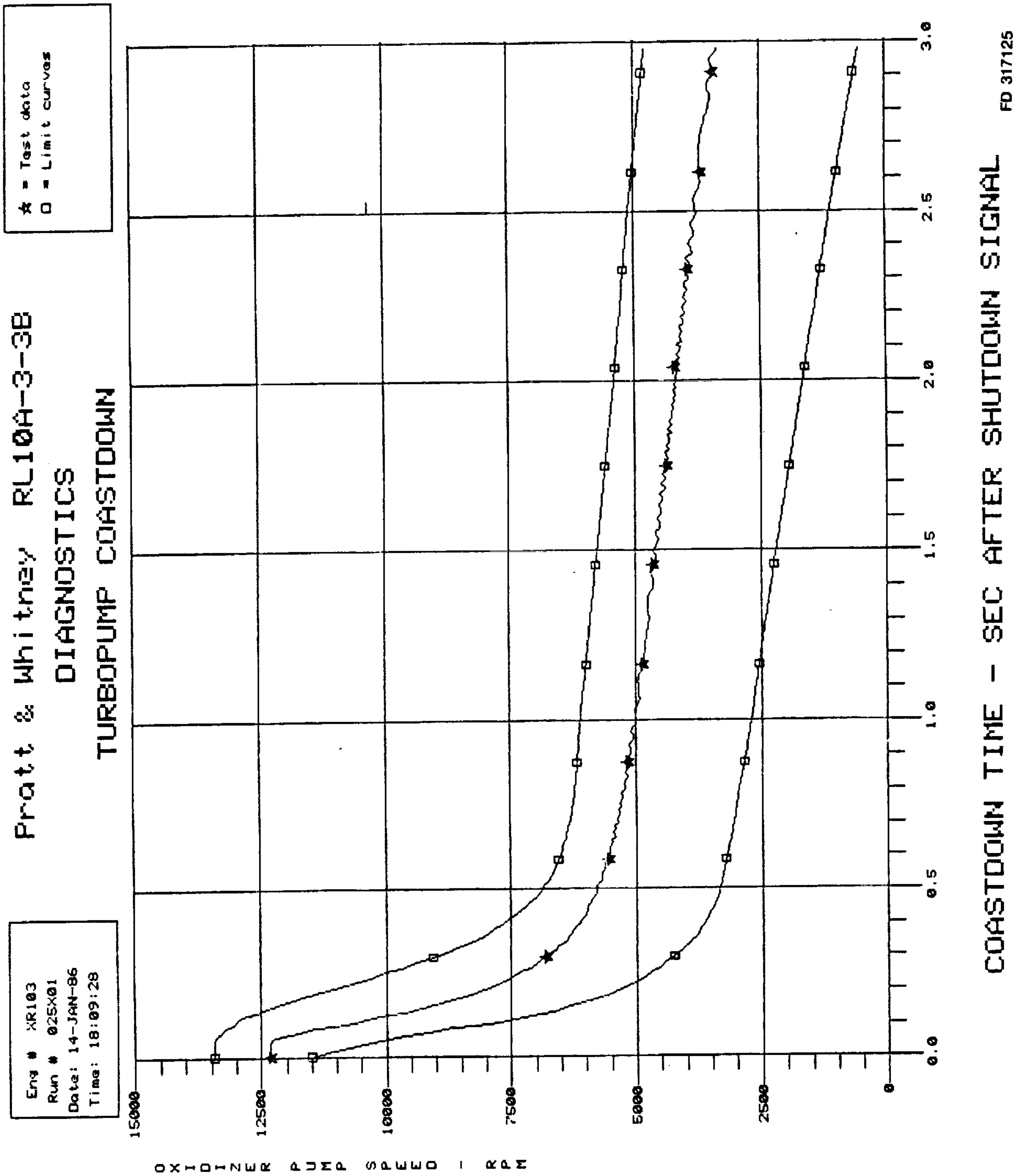

Figure V-18. Turbopump Coastdown

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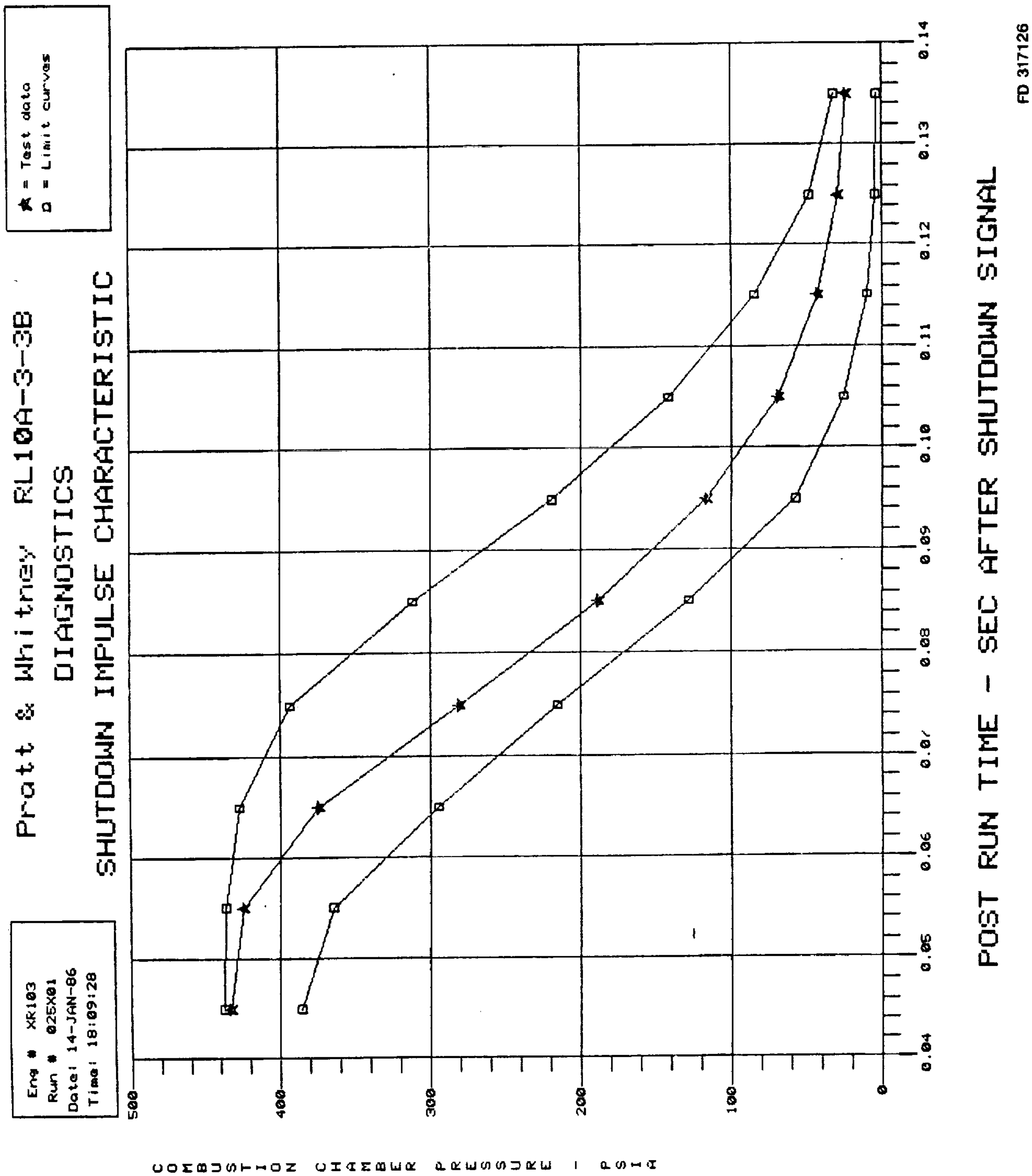

Figure V-19. Shutdown Impulse Characteristic

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Diagnostic Plots — Summary Sheet

Start Transient

Test 1: Transient Fuel Pump Performance

Check to see if the fuel pump is performing properly during the start transient.

Fuel venturi upstream pressure vs oxidizer pump speed (Figure V-13)

Steady State

Test 2: Steady-State Performance

Check to see that thrust control is functioning properly and engine has reserve power.

Combustion chamber pressure vs time 100 < Time < 450 seconds (Figure V-14)

Test 3: Fuel Pump Performance

Check to see if the fuel pump is operating properly.

Fuel venturi upstream pressure vs oxidizer pump speed 11800 < RPM-11 < 12800 rpm (Figure V-15)

Test 4: Heat Exchanger Performance

Check of the heat exchanger performance of the nozzle jacket.

Fuel turbine inlet temperature vs oxidizer pump speed 11800 < RPM-11 < 12800 rpm (Figure V-16)

Test 5: Oxidizer Pump Performance

Check of the oxidizer pump performance.

Oxidizer pump pressure rise vs oxidizer pump speed 11800 < RPM-11 < 12800 rpm (Figure V-17)

Shutdown Transient

Test 6: Turbopump Coastdown

Check of turbomachinery coastdown which could possibly indicate a bearing or gear train failure or deterioration.

Oxidizer pump speed vs time 0.00 < Time < 3.00 seconds (Figure V-18)

Test 7: Shutdown Impulse Characteristic

Check of valve closure and normal engine deceleration.

Combustion chamber pressure vs time 0.04 < Time < 0.14 second (Figure V-19)

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4. Nozzle Candidate Material Samples

During the Qualification Test program several samples of materials to be evaluated for use in RL10 extendable nozzles were mounted on the engine. Running of samples was not related to the Qual Test. Their testing is mentioned here since they were piggybacked with the Qual Test and were run during this test series. Accumulated times on the samples are shown in Table V-5.

Table V-5. *Sample Materials Run Times*

Sample Type	*No. Runs*	*Total Run Time (Sec)*
Alloy "Y"	14	2846.8
Uncoated Columbium	6	1203.3
Coated Columbium	23	4450.9

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The samples can be seen mounted on the engine in Figures V-1 and V-2.

5. Performance Summary

5.1 Engine Performance

Engine XR103-2 completed 23 tests with a run time of 5693.4 seconds; 4533.6 seconds were completed during the official qualification testing phase. Figure V-20 shows the average specific impulse is 435.3 sec at 15.0K lb and 6.0 mixture ratio, which is 1.0 second below the RL10A-3-3B average specific impulse from engines FX143-33, FX144-28, XR101-1, XR102-2, P642033, P642034, P642045, and P642046. A nominal specific impulse of 436.0 ± 2.7 sec is used in the RL10A-3-3B specification. Table V-6 presents a summary of the test program and Table V-7 is a summary of the engine performance for each run.

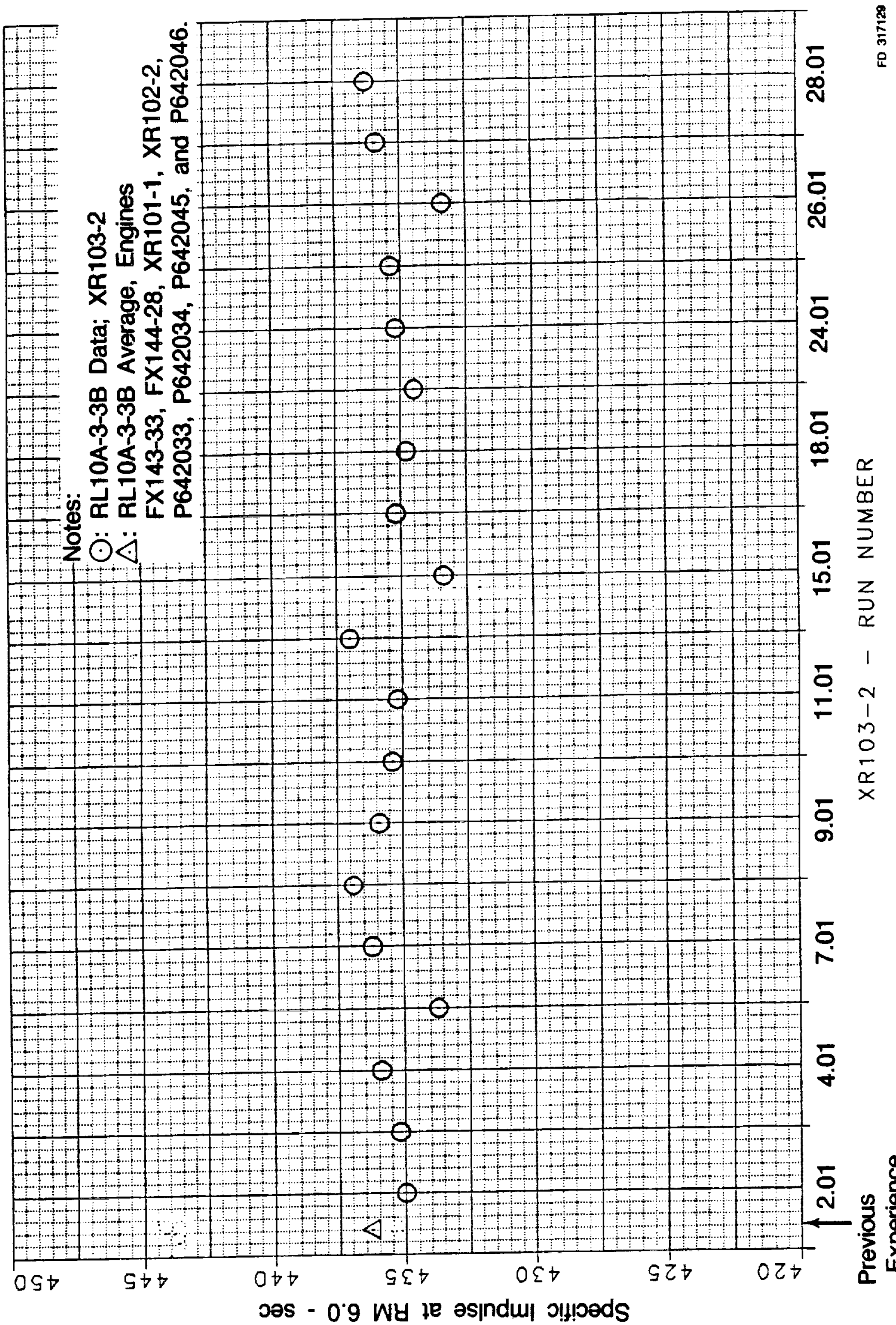

Figure V-20. RL10A-3-3B Engine Performance

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Table V-6. *RL10A-3-3B Qual Test Summary*

Item	Units	Engine No. XR103-2								
		12-18-85	12-19-85	12-20-85	12-20-85	12-23-85	1-2-86	1-2-86	1-3-86	1-3-86
Run No.		2.01	3.01	4.01	5.01	6.01	7.01	8.01	9.01	10.01
Tape No.		F17625	F17626	F17627	F17628	F17629	F17630	F17631	F17632	F17633
Run Duration	sec	340.1	451.2	451.0	451.1	150.0	150.0	151.1	150.0	151.1
Accumulated Hot Time	sec	340.1	791.3	1242.3	1693.4	1843.4	1993.4	2144.5	2294.5	2445.6
Prestart Duration Fuel /Oxidizer	sec	40.0/220.0	40.0/220.0	40.0/220.0	40.0/220.0	36.2/165.2	45.0/165.0	5.0/5.0	36.0/165.0	5.0/5.0
Oxidizer Pump Inlet Pressure Prestart/Start	psia	43.9/44.3	44.0/44.1	43.9/44.2	43.9/44.0	68.4/68.6	68.1/66.1	65.8/66.0	68.5/68.6	68.5/68.6
Oxidizer Pump Inlet Temperature Prestart/Start	°R	176.1/175.9	176.1/175.8	176.4/175.8	176.0/175.8	185.4/185.3	184.7/184.7	184.7/184.7	185.3/185.3	185.1/185.2
Fuel Pump Inlet Pressure Prestart/Start	psia	27.5/27.5	27.7/27.8	27.6/27.4	27.6/27.7	31.6/31.5	24.0/24.5	24.5/24.5	31.6/31.4	31.4/31.3
Fuel Pump Inlet Temperature Prestart/Start	°R	38.6/38.8	38.9/38.7	38.9/38.7	38.8/38.9	39.5/39.4	38.8/39.2	38.9/38.9	39.3/39.2	39.4/39.2
Oxidizer Pump Housing Temperature Prestart/Start	°R	463/183	455/183	455/183	458/181	441/189	451/190	193/193	441/189	195/193
Fuel Pump Housing Temperature Prestart/Start	°R	460/78	446/82	449/81	457/80	444/84	458/83	97/77	449/81	97/70
Fuel Turbine Inlet Temperature Prestart/Start	°R	505/500	495/490	500/495	487/482	473/470	484/480	432/432	471/467	428/428
Mae West Skin Temperature Prestart/Start	°R	NAP	595/453	NAP	552/229	530/209	543/265	455/430	529/259	458/451
Nozzle Skin Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Fuel Pump Discharge Line Temp. Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Oxidizer Flow Control Valve Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Oxygen Injector Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Time to Accelerate (uncorrected)	sec	1.809	1.757	1.799	1.722	1.768	2.432	2.055	1.731	1.576
Start Impulse to 3 sec (uncorrected)	lb-sec	19,790	20,788	20,066	21,365	20,984	11,438	17,164	21,562	23,804
Fuel Pump Discharge Pressure at Interstage Cooldown Valve at SV-10 Start to Close/Closed	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV

Table V-6. RL10A-3-3B Qual Test Summary (Continued)

Engine No. XR103-2

Item	*Units*	*12-18-85*	*12-19-85*	*12-20-85*	*12-20-85*	*12-23-85*	*1-2-86*	*1-2-86*	*1-3-86*	*1-3-86*
Sparks to Light		1	1	1	1	2	2	1	2	1
Oxidizer Flow Control Valve Cracking Pressure	psid	79	81	80	79	79	79	82	84	85
Min NPSP Fuel/Oxidizer	sec	2.81/3.12	1.30/1.65	3.02/2.05	1.64/2.17	2.04/3.49	0.89/3.25	0.01/2.50	2.75/3.51	1.89/2.97
Time from Start Solenoid Voltage Up to	sec	—	—	—	—	—	—	—	—	—
Oxidizer Flow Control Valve Cracking	sec	1.470	1.505	1.454	1.385	1.428	2.087	1.665	1.400	1.238
Interstage Cooldown Valve Closed	sec	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Gaseous Oxygen to Liquid Oxygen	sec	1.657	1.594	1.601	1.640	1.607	2.288	1.849	1.565	1.398
Decel Time	sec	NAV	NAV	0.141	0.144	0.143	0.141	0.144	0.143	0.148
Shutdown Impulse (corrected)	lb/sec	NAV	NAV	1254	1304	1254	1255	1355	1266	1257
Time Start Solenoid Voltage Up/Start Solenoid Voltage Down	sec	254.444 594.572	255.995 707.227	247.415 698.464	260.692 711.838	195.560 345.571	198.044 348.102	378.115 529.214	201.261 351.263	381.276 332.391
Steady State Thrust	lbs	15.159	15.212	NAV	152.48	152.16	153.09	153.32	153.15	153.13
Mixture Ratio		6.013	6.021	NAV	6.048	6.044	6.042	6.030	6.064	6.028
Impulse at 5.0	sec	435.0	435.2	NAV	435.9	—	—	—	—	—
Stability	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Comments:		TRIM	TRIM CK	START Q/T			1st Burn C/D	Relite C/D	1st Burn C/D	Relite C/D

Item	*Units*	*1-3-86*	*1-3-86*	*1-8-86*	*1-8-86*	*1-9-86*	*1-9-86*	*1-9-86*	*1-10-86*	*1-10-86*
Run No.		11.01	12.01	13.01	14.01	15.01	16.01	17.01	18.01	19.01
Tape No.		F17634	F17635	F17636	F17637	F17638	F17639	F17640	F17641	F17642
Run Duration	sec	150.0	151.0	100.0	—	150.0	120.0	6.0	150.0	150.0
Accumulated Hot Time	sec	2595.6	2746.6	2846.6	—	2996.6	3116.6	3122.6	3272.6	3422.6
Prestart Duration Fuel/Oxidizer	sec	36.0/250.0	5.0/5.0	40.0/220.0	5.0/5.0	45.0/250.0	5.0/8.0	5.0/3.0	40.0/220.0	5.0/8.0
Oxidizer Pump Inlet Pressure Prestart/Start	psia	31.5/31.6	31.2/31.3	43.8/44.2	/43.8	31.9/32.0	32.2/32.0	31.8/32.0	44.1/44.3	44.1/44.2
Oxidizer Pump Inlet Temperature Prestart/Start	°R	171.5/171.3	171.1/171.2	176.0/175.7	/175.7	172.2/171.6	171.3/171.3	171.2/171.3	178.0/176.3	175.7/176.2
Fuel Pump Inlet Pressure Prestart/Start	psia	31.4/31.4	31.4/31.0	27.5/27.5	/27.2	24.4/24.3	24.3/24.2	24.5/24.2	27.5/27.5	27.4/27.4
Fuel Pump Inlet Temperature Prestart/Start	°R	39.2/39.4	39.4/39.2	38.7/38.8	/39.0	38.8/38.9	39.0/39.2	38.7/38.7	38.9/39.1	
Oxidizer Pump Housing Temperature Prestart/Start	°R	452/177	186/180	458/180	458/190	419/176	177/176	180/179	429/180	182/180
Fuel Pump Housing Temperature Prestart/Start	°R	451/76	97/67	543/88	543/96	434/80	96/73	92/70	448/85	98/74

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Table V-6. RL10A-3-3B Qual Test Summary (Continued)

Item	Units	Engine No. XR103-2								
		1-3-86	1-3-86	1-8-86	1-8-86	1-9-86	1-9-86	1-9-86	1-10-86	1-10-86
Fuel Turbine Inlet Temperature Prestart/Start	°R	471/468	418/418	671/649	671/413	465/462	426/427	425/426	475/470	427/428
Mae West Skin Temperature Prestart/Start	°R	548/286	457/454	649/423	463/459	518/254	451/445	448/448	534/248	452/444
Nozzle Skin Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Fuel Pump Discharge Line Temp. Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Oxidizer Flow Control Valve Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Oxygen Injector Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Time to Accelerate (uncorrected)	sec	1.523	1.417	1.899	NAP	1.927	1.669	1.673	1.832	1.631
Start Impulse to 3 sec (uncorrected)	lb-sec	24,356	25,732	19,143	NAP	18,791	22,561	22,315	19,731	23,173
Fuel Pump Discharge Pressure at Interstage Cooldown Valve at SV-10 Start to Close/Closed	psia	NAV	NAV	NAV	NAP	NAV	NAV	NAV	NAV	NAV
Sparks to Light		1	1	1	NAP	1	2	1	1	1
Oxidizer Flow Control Valve Cracking Pressure	psid	80	81	77	NAP	79	81	NAV	80	81
Min NPSP Fuel/Oxidizer	sec	4.9/0.66	4.4/0.48	0.25/2.45	NAP	−0.66/0.31	−0.65/0.73	−0.4/0.52	2.5/1.5	2.36/1.36
Time from Start Solenoid Voltage Up	sec	—	—	—	—	—	—	—	—	—
Oxidizer Flow Control Valve Cracking	sec	1.137	1.022	1.498	NAP	1.520	1.235	1.255	1.485	1.227
Interstage Cooldown Valve Closed	sec	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Gaseous Oxygen to Liquid Oxygen	sec	1.333	1.213	1.729	NAP	1.707	1.430	1.446	1.674	1.390
Decel Time	sec	0.128	0.129	0.128	NAP	0.146	0.143	NAP	0.128	0.131
Shutdown Impulse (corrected)	lb/sec	1291	1271	1271	NAP	1331	1318	NAP	1288	1261
Time Start Solenoid Voltage Up/Start Solenoid Voltage Down	sec	284.796 434.798	464.812 615.851	284.179 384.181	504.197 504.696	281.584 431.587	464.603 581.601	611.616 617.651	251.154 401.156	431.172 581.171
Steady State Thrust	lb	15,305	15,307	15,241	NAP	15,240	15,258	NAP	15,331	15,335
Mixture Ratio		5.876	5.817	5.931	NAP	5.850	5.866	NAP	5.919	5.894
Impulse at 5.0	sec	—	—	—	—	—	—	—	—	—
Stability	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Comments:		1st Burn C/D	Relite C/D	Hot Chamb/ Solenoid	Lo-Lo Pc Abort No Lite	1st Burn C/D Cold Cham/Sol	Relite C/D	Relite C/D Non Q/T Run	1st Burn C/D	Relite C/D

Table V-6. RL10A-3-3B Qual Test Summary (Continued)

Engine No. XR103-2

Item	Units	1-10-86	1-10-86	1-10-86	1-10-86	1-13-86	1-14-86	1-14-86	1-15-86	1-15-86
Run No.		20.01	21.01	22.01	23.01	24.01	25.01	26.01	27.01	28.01
EB7 No.		F17643	F17644	F17645	F17646	F17648	F17649	F17650	F17651	F17652
Run Duration	sec	6.2	60.0	60.0	6.2	510.1	450.9	350.8	476.5	350.1
Accumulated Hot Time	sec	3428.8	3488.8	3548.8	3555.0	4065.1	4516.0	4866.8	5343.3	5693.4
Prestart Duration Fuel/Oxidizer	sec	5.0/3.0	40.0/220.0	5.0/10.0	5.0/3.0	40.0/220.0	40.0/220.0	40.0/220.0	40.0/220.0	40.0/220.0
Oxidizer Pump Inlet Pressure Prestart/Start	psia	44.0/44.3	43.8/44.1	43.7/43.9	43.8/44.0	44.0/44.2	43.9/44.2	43.6/44.1	42.6/44.1	44.1/44.5
Oxidizer Pump Inlet Temperature Prestart/Start	°R	176.0/176.4	176.7/176.0	176.0/175.9	175.9/175.9	176.3/175.9	175.9/175.8	175.9/175.8	175.9/175.7	175.8/175.6
Fuel Pump Inlet Pressure Prestart/Start	psia	27.6/27.3	27.5/27.7	27.6/27.6	27.6/27.6	27.6/27.6	27.6/27.4	27.6/27.6	27.6/27.6	27.5/27.4
Fuel Pump Inlet Temperature Prestart/Start	°R	39.0/39.1	38.9/39.0	38.7/39.0	38.7/38.9	38.7/38.8	38.9/38.7	38.6/38.9	38.6/38.7	38.7/38.9
Oxidizer Pump Housing Temperature Prestart/Start	°R	184/184	461/181	198/184	202/194	438/181	443/183	453/183	438/182	461/182
Fuel Pump Housing Temperature Prestart/Start	°R	92/69	467/81	117/81	110/76	447/84	440/83	446/83	428/82	460/83
Fuel Turbine Inlet Temperature Prestart/Start	°R	424/425	497/492	414/418	412/414	473/469	487/485	496/491	477/540	508/504
Mae West Skin Temperature Prestart/Start	°R	446/447	554/291	457/450	466/465	561/232	528/236	539/238	529/232	550/245
Nozzle Skin Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Fuel Pump Discharge Line Temp. Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Oxidizer Flow Control Valve Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Oxygen Injector Temperature Prestart/Start	°R	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Time to Accelerate (uncorrected)	sec	1.611	1.724	1.565	1.523	1.772	1.797	1.707	1.731	1.749
Start Impulse to 3 sec (uncorrected)	lb-sec	23,197	21,450	23,760	24,521	20,761	20,284	21,534	21,274	20,959
Fuel Pump Discharge Pressure at Interstage Cooldown Valve at SV-10 Start to Close/Closed	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV

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Table V-6. RL10A-3-3B Qual Test (Continued)

		Engine No. XR103-2								
Item	Units	1-10-86	1-10-86	1-10-86	1-10-86	1-13-86	1-14-86	1-14-86	1-15-86	1-15-86
Sparks to Light		1	1	1	1	1	1	1	1	1
Oxidizer Flow Control Valve Cracking Pressure	psid	79	79	80	75	79	80	80	79	85
Min NPSP Fuel/Oxidizer	sec	3.07/1.50	1.1/2.0	1.2/2.6	2.2/3.0	1.8/1.6	2.1/1.95	2.6/1.85	2.6/2.2	2.24/2.32
Time from Start Solenoid Voltage Up	sec	—	—	—	—	—	—	—	—	—
Oxidizer Flow Control Valve Cracking	sec	1.244	1.376	1.212	1.137	1.433	1.426	1.367	1.395	1.421
Interstage Cooldown Valve Closed	sec	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Gaseous Oxygen to Liquid Oxygen	sec	1.420	1.553	1.398	1.336	1.612	1.645	1.555	1.585	1.596
Decel Time	sec	NAP	0.141	0.134	NAP	0.137	0.133	0.134	0.131	0.132
Shutdown Impulse (corrected)	lb/sec	NAP	1275	1285	NAP	1341	1223	1288	1276	1276
Time Start solenoid Voltage Up/Start Solenoid Voltage Down	sec	611.185 617.405	254.833 314.832	434.851 494.847	614.864 621.087	247.027 757.142	253.411 704.315	252.364 603.207	262.642 739.096	252.207 602.291
Steady State Thrust	lbs	NAP	15,358	15,374	NAP	15,350	15,391	15,317	15,440	15,416
Mixture Ratio		NAP	5.885	5.903	NAP	5.755	5.862	5.911	6.746	6.012
Impulse at 6.0	sec	—	—	—	—	435.2	435.4	—	435.9	436.3
Stability	+psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Comments:		Relite C/D Non Q/T Run	1st Burn C/D	Relite C/D	Relite C/D Non Q/T Run	NPSP and CAL	CAL	Min S/S Fuel NPSP	End Q/T Cal	Post Q/T Cal

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Table V-7. Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary

Engine No. XR103-2

Item	Units							
Stand		E-6	E-6	E-6	E-6	E-6	E-6	E-6
Run No.		2.01	3.01	4.01	5.01	6.01	7.01	8.01
Date		12-18-85	12-19-85	12-20-85	12-20-85	12-23-85	1-2-86	1-2-86
Hot Time	sec	340.1	451.2	451.0	451.1	150.0	150.0	151.1
Total Hot Time	sec	340.1	791.3	1242.3	1693.4	1843.4	1993.4	2144.5
Fuel Pump Inlet Pressure — Static	psia	27.5	27.8	27.4	27.7	31.5	24.5	24.5
Fuel Pump Inlet Temperature	°R	38.8	38.7	38.7	38.9	39.4	37.2	38.9
LOX Pump Inlet Pressure — Static	psia	44.3	44.1	44.2	44.0	68.6	66.1	66.0
LOX Pump Inlet Temperature	°R	175.9	175.8	175.8	175.8	185.3	184.7	184.7
Oxidizer Pump Housing Temperature Prestart/Start	°R	463/183	455/183	455/183	458/181	441/189	451/190	193/193
Fuel Pump Housing Temperature Prestart/Start	°R	460/78	446/82	449/81	457/80	444/84	458/83	97/77
Fuel Turbine Inlet Temperature Prestart/Start	°R	505/500	495/490	500/495	487/482	473/470	484/480	432/432
Accel. Time (to 90% Thrust) Uncorrected	sec	1.809	1.757	1.799	1.722	1.768	2.432	2.055
Accel. Time (to 90% Thrust) Corrected	sec	1.836	1.858	1.804	1.797	1.806	1.810	1.422
Starting Impulse (to 2 sec) Uncorrected	lbs-sec	19,790	20,788	20,066	21,365	20,984	11,438	17,144
Starting Impulse (to 2 sec) Corrected	lbs-sec	19,393	19,303	19,994	20,248	20,416	20,104	26,593
Peak Transient Thrust 17,740 max	lbs	14,890	14,958	14,850	15,031	15,007	14,570	14,903
Percent Thrust Overshoot	%	−0.731	−0.283	−0.998	0.208	0.046	−2.867	−0.644
Maximum Rate of Thrust Increase Nap/250	lbs/mili-sec	1224/93	1338/119	—	1079/105	1067/213	1280/116	831/111
Maximum Start Oxidizer Flow 40.5 max	lbs/sec	29.4	30.0	29.8	29.9	30.5	30.3	29.4
Maximum Start Fuel Flow 7.1 max	lbs/sec	4.9	4.7	4.7	4.8	4.6	4.2	4.7
External Power at Maximum Demand 30/8.5 max	Volts/Amps	23.8/6.0	24.4/6.1	16.8/5.0	23.3/6.0	22.0/6.3	24.8/6.1	24.2/6.1
Fuel Pump Discharge Pressure and Interstage Cooldown Valve Start to Close	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Oxidizer Flow Control Valve Cracking Pressure	psid	79	81	80	79	79	79	82
Sparks to Light		1	1	1	1	2	2	1
Fuel Pump Inlet Pressure — Total	psia	25.6	25.4	25.6	25.5	30.6	23.4	23.3
Fuel Pump Inlet Temperature	°R	37.8	38.2	38.1	38.1	39.0	37.9	37.9
LOX Pump Inlet Pressure — Total	psia	41.1	41.3	41.5	41.1	65.5	62.9	63.0
LOX Pump Inlet Temperature	°R	175.1	175.0	175.1	175.2	184.6	184.3	184.4
Chamber Pressure (Injector Face Static)	psia	428.6	429.5	430.9	430.2	429.7	430.2	430.6

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Table V-7. *Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)*

Item	Units	Engine No. XR103-2						
Actual Mixture Ratio		6.013	6.021	5.246	6.048	6.044	6.042	6.030
Trim Mixture Ratio		—	—	—	—	—	—	—
Percent of Trim Mixture Ratio	%	—	—	—	—	—	—	—
Thrust at 200,000 ft	lbs	15,159	15,212	15,003	15,248	15,216	15,309	15,332
Trim Thrust at 200,000 ft	lbs	15,004	15,006	NAV	15,013	15,012	15,012	15,008
Percent of Trim Thrust	%	1.03	1.08	NAV	1.56	1.355	1.981	2.154
Specific Impulse	sec	434.8	434.7	439.2	435.5	433.4	435.9	436.7
Specific Impulse at r = 6.0	sec	435.0	435.2	435.1	435.9	433.7	436.2	436.9
Specific Impulse Efficiency at r = 6.0	%	94.7	94.7	NAV	94.7	94.42	94.96	95.12
Characteristic Vel Efficiency at r = 6.0 (Inj Face Pc)	%	98.0	97.9	NAV	97.8	97.56	97.64	97.72
Thrust Coeff Efficiency at r = 6.0 (Inj Face Pc)	%	96.6	96.7	NAV	96.8	96.79	97.26	97.33
Steady State LOX Pump Speed	rpm	12,122	12,174	12,553	12,145	12,181	12,178	12,195
Coolant Outlet Temperature - Steady State Fuel Turbine Inlet Temp	°R	448.2	451.9	411.9	451.5	453.4	449.8	448.6
ΔT/ΔT' at r = 6.0 (Corrected)	%	101.9	102.7	NAV	101.8	102.9	102.4	102.1
Hydrogen Leakage Total/Gearbox 0.15 max	lbs/sec	0.063/0.050	0.068/0.055	0.077/0.065	0.066/0.053	0.064/0.047	0.062/0.049	0.061/0.049
Chamber Pressure	psia	—	—	—	—	—	—	—
Mixture Ratio		—	—	—	—	—	—	—
Thrust Control Body Pressure		—	—	—	—	—	—	—
Chamber Pressure Ratio (Inj Face/Igniter Tap)		0.9912	0.9909	0.9932	0.9904	0.9911	0.9898	0.9903
Oxidizer Flow Control Valve "K" Factor/Propellant Utilization Valve Angle		5.801/−21.4	6.16/−10.7	9.92/35.6	5.54/−15.6	6.53/−8.5	6.05/−9.01	6.07/−9.12
Fuel Injector Effective Area (Inj Face Pc)		2.388	2.427	3.502	2.398	2.459	2.403	2.394
LOX Injector Effective Area (Inj Face Pc)		0.757	0.767	0.760	0.755	0.760	0.738	0.732
Fuel Tank/Pressurization Bleed Flow at r = 6.0	ft/sec	NAP	0.757	0.109	NAP	0.110	NAP	NAP
Stability (Pc Amplitude)	±psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Thrust Tare Prerun/Postrun	lbs	−280/−235	−284/−234	−273/−233	−248/−186	−257/−224	−295/−240	−295/−240
Helium Consumption 0.05 max	lbs	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Shutdown Impulse (at 200,000 ft) Uncorrected	lbs/sec	1137	1096	1138	1195	1184	1175	1262
Shutdown Impulse (at 200,000 ft) Corrected	lbs/sec	1211	1183	1254	1304	1254	1255	1355
Decel. Time (Meas at S.L. Cond)	sec	0.117	0.110	0.141	0.144	0.143	0.141	0.144
Valve Helium Supply Pressure 440 - 500	psia	474.7	473.6	466.1	468.0	467.7	467.2	466.4
Solenoid Voltage 20-30	volts	26.7	26.8	18.3	27.0	26.7	27.2	27.3
Main Fuel Shutoff Valve Delta Closing Time	sec	0.060	0.055	0.052	0.050	0.054	0.053	0.053
Oxidizer Inlet Valve Delta Closing Time	sec	0.132	0.133	0.211	0.250	0.210	0.203	0.198

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Table V-7. Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)

Engine No. XR103-2

Item	Units							
Stand		E-6	E-6	E-6	E-6	E-6	E-6	E-6
Run No.		9.01	10.01	11.01	12.01	13.01	14.01	15.01
Date		1-3-86	1-3-86	1-3-86	1-3-86	1-8-86	1-8-86	1-9-86
Hot Time	sec	150.0	151.1	150.0	151.0	100.0	(No Lite)	150.0
Total Hot Time	sec	2294.5	2445.6	2595.6	2746.6	2846.6	—	2996.6
Fuel Pump Inlet Pressure — Static	psia	31.4	31.3	31.4	31.0	27.5	NAP	24.3
Fuel Pump Inlet Temperature	°R	39.2	39.2	39.4	39.2	38.8	NAP	38.9
LOX Pump Inlet Pressure — Static	psia	68.6	68.6	31.6	31.3	44.2	NAP	32.0
LOX Pump Inlet Temperature	°R	185.3	185.2	171.3	171.2	175.7	NAP	171.6
Oxidizer Pump Housing Temperature Prestart/Start	°R	441/189	195/193	452/177	186/180	458/180	NAP	419/176
Fuel Pump Housing Temperature Prestart/Start	°R	449/81	97/70	451/76	97/67	543/88	NAP	434/80
Fuel Turbine Inlet Temperature Prestart/Start	°R	471/467	428/428	471/468	418/418	671/649	NAP	465/462
Accel. Time (to 90% Thrust) Uncorrected	sec	1.731	1.576	1.523	1.417	1.899	NAP	1.927
Accel. Time (to 90% Thrust) Corrected	sec	1.808	1.681	1.861	1.759	1.939	NAP	NAV
Starting Impulse (to 2 sec) Uncorrected	lbs-sec	21,562	23,804	24,356	25,732	19,143	NAP	18,791
Starting Impulse (to 2 sec) Corrected	lbs-sec	20,425	22,204	19,272	20,495	18,560	NAP	63,456
Peak Transient Thrust 17,740 max	lbs	15,200	15,129	15,174	15,180	15,185	NAP	14,949
Percent Thrust Overshoot	%	1.335	0.861	1.159	1.198	1.234	NAP	−0.341
Maximum Rate of Thrust Increase Nap/250	lbs/mili-sec	1374/126	1158/110	1088/87	1459/107	1022/109	NAP	1290/98
Maximum Start Oxidizer Flow 40.5 max	lbs/sec	30.7	30.1	29.4	29.3	30.5	NAP	29.4
Maximum Start Fuel Flow 7.1 max	lbs/sec	4.75	4.83	5.1	5.05	4.52	NAP	4.88
External Power at Maximum Demand 30/8.5 max	Volts/Amps	24.9/6.2	26.6/6.1	25.0/6.0	25.1/5.95	25.4/5.4	NAP	23.3/7.8
Fuel Pump Discharge Pressure and Interstage Cooldown Valve Start to Close	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Oxidizer Flow Control Valve Cracking Pressure	psid	84	85	80	81	77	NAP	79
Sparks to Light		2	1	1	1	1	NAP	1
Fuel Pump Inlet Pressure — Total	psia	30.5	30.6	30.2	30.2	26.1	NAP	23.1
Fuel Pump Inlet Temperature	°R	38.7	38.7	38.6	38.6	38.0	NAP	37.9
LOX Pump Inlet Pressure — Total	psia	65.6	65.7	28.1	28.1	40.6	NAP	29.0
LOX Pump Inlet Temperature	°R	184.7	184.8	170.7	170.8	175.2	NAP	170.8
Chamber Pressure (Injector Face Static)	psia	430.4	432.3	431.1	430.9	429.8	NAP	431.5

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Table V-7. Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)

Item	Units	Engine No. XR103-2						
Actual Mixture Ratio		6.064	6.028	5.876	5.817	5.931	NAP	5.850
Trim Mixture Ratio		—	—	—	—	—	—	—
Percent of Trim Mixture Ratio	%	—	—	—	—	—	—	—
Thrust at 200,000 ft	lbs	15,315	15,313	15,305	15,307	15,241	NAP	15,240
Trim Thrust at 20,000 ft	lbs	15,018	15,008	14,965	14,947	14,981	NAP	14,957
Percent of Trim Thrust	%	1.98	2.03	2.27	2.41	1.74	NAP	1.89
Specific Impulse	sec	435.4	435.1	436.2	438.4	435.0	NAP	434.6
Specific Impulse at r = 6.0	sec	435.9	435.4	435.2	437.0	—	NAP	433.4
Specific Impulse Efficiency at r = 60	%	94.90	94.78	94.75	95.13	—	NAP	94.37
Characteristic Vel Efficiency at r = 6.0 (Inj Face Pc)	%	97.62	97.85	97.34	97.58	—	NAP	97.40
Thrust Coeff Efficiency at r = 6.0 (Inj Face Pc)	%	97.22	96.86	97.33	97.49	—	NAP	96.89
Steady State LOX Pump Speed	rpm	12,191	12,200	12,286	12,288	12,216	NAP	12,286
Coolant Outlet Temperature - Steady State Fuel Turbine Inlet Temperature	°R	444.7	442.3	434.7	432.8	437.2	NAP	441.7
ΔT/ΔT' at r = 6.0 (Corrected)	%	101.0	100.3	101.5	101.2	—	NAP	103.5
Hydrogen Leakage Total/Gearbox 0.15 max	lbs/sec	0.065/0.048	0.066/0.049	0.066/0.050	0.063/0.047	0.060/0.047	NAP	0.073/0.055
Chamber Pressure	psia	—	—	—	—	—	—	—
Mixture Ratio		—	—	—	—	—	—	—
Thrust Control Body Pressure		—	—	—	—	—	—	—
Chamber Pressure Ratio (Inj Face/Igniter Tap)		0.9915	0.9961	0.9902	0.9900	0.9879	NAP	0.9931
Oxidizer Flow Control Valve "K" Factor/Propellant Utilization Valve Angle		6.42/−8.59	6.461/−8.65	5.87/−8.59	5.95/−8.64	6.13/−8.70	NAP	6.38/−7.34
Fuel Injector Effective Area (Inj Face Pc)		2.3928	2.441	2.360	2.371	2.366	NAP	2.436
Oxidizer Injector Effective Area (Inj Face Pc)		0.7406	0.748	0.736	0.725	0.733	NAP	0.745
Fuel Tank/Pressurization Bleed Flow at r = 5.0	ft/sec	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Stability (Pc Amplitude)	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Thrust Tare Prerun/Postrun	lbs	−250/−207	−250/−207	−279/−225	−279/−225	−267/−256	NAP	−264/—
Helium Consumption 0.05 max	lbs	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Shutdown Impulse (at 200,000 ft) Uncorrected	lbs/sec	1207	1188	1215	1182	1088	NAP	1461
Shutdown Impulse (at 200,000 ft) Corrected	lbs/sec	1266	1257	1291	1271	1271	NAP	1331
Decel. Time (Meas at S.L. Cond)	sec	0.143	0.148	0.128	0.129	0.128	NAP	0.146
Valve Helium Supply Pressure 440-500	psia	472.7	474.2	473.3	471.9	471.5	NAP	471.4
Solenoid Voltage 20-30	volts	27.1	27.0	27.3	27.2	27.6	NAP	25.3
Main Fuel Shutoff Valve Delta Closing Time	sec	0.056	0.054	0.052	0.052	0.047	NAP	0.070
Oxidizer Inlet Valve Delta Closing Time	sec	0.205	0.194	0.285	0.253	0.243	NAP	0.280

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Table V-7. Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)

Item	Units	Engine No. XR103-2						
Stand		E-6	E-6	E-6	E-6	E-6	E-6	E-6
Run No.		16.01	17.01	18.01	19.01	20.01	21.01	22.01
Date		1-9-86	1-9-86	1-10-86	1-10-86	1-10-86	1-10-86	1-10-86
Hot Time	sec	120.0	6.0	150.0	150.0	6.2	60.0	60.0
Total Hot Time	sec	3116.6	3122.6	3272.6	3422.6	3428.8	3488.8	3548.8
Fuel Pump Inlet Pressure — Static	psia	24.2	24.2	27.5	27.4	27.3	27.7	27.6
Fuel Pump Inlet Temperature	°R	39.2	39.2	38.7	39.1	39.1	39.0	39.0
LOX Pump Inlet Pressure — Static	psia	32.0	32.0	44.3	44.2	44.3	44.1	43.9
LOX Pump Inlet Temperature	°R	171.3	171.3	176.3	176.2	176.4	176.0	175.9
LOX Pump Housing Temperature Prestart/Start	°R	177/176	180/179	429/180	182/180	185/184	461/181	198/184
Fuel Pump Housing Temperature Prestart/Start	°R	96/73	92/70	448/85	96/74	90/69	467/81	117/81
Fuel Turbine Inlet Temperature Prestart/Start	°R	426/427	425/426	475/470	427/428	424/425	497/492	414/418
Accel. Time (to 90% Thrust) Uncorrected	sec	1.669	1.673	1.832	1.631	1.611	1.724	1.565
Accel. Time (to 90% Thrust) Corrected	sec	NAV	NAV	1.818	1.594	1.528	1.780	1.594
Starting Impulse (to 2 sec) Uncorrected	lbs-sec	22,561	22,315	19,731	23,173	23,197	21,450	23,760
Starting Impulse (to 2 sec) Corrected	lbs-sec	69,535	68,862	19,931	23,735	24,471	20,613	23,319
Peak Transient Thrust 17,740 max	lbs	15,051	15,084	15,084	15,074	15,205	15,270	15,203
Percent Thrust Overshoot	%	0.343	0.561	0.561	0.494	1.370	1.797	1.355
Maximum Rate of Thrust Increase Nap/250	lbs/mili-sec	1396/108	1079/84	1177/100	1311/77	1173/117	905/88	703/98
Maximum Start Oxidizer Flow 40.5 max	lbs/sec	29.6	29.3	30.4	29.6	29.7	30.3	29.9
Maximum Start Fuel Flow 7.1 max	lbs/sec	4.9	5.0	4.7	4.9	4.9	4.7	4.9
External Power at Maximum Demand 30/8.5 max	Volts/Amps	23.8/7.4	24.8/7.2	24.0/6.1	24.8/6.1	23.2/6.0	22.9/6.1	24.0/6.0
Fuel Pump Discharge Pressure and Interstage Cooldown Valve Start to Close	psia	NAV	NAV	NAV	NAV	NAV	NAP	NAV
Oxidizer Flow Control Valve Cracking Pressure	psid	81	NAV	80	81	79	79	80
Sparks to Light		2	1	1	1	1	1	1
Fuel Pump Inlet Pressure — Total	psia	23.1	NAP	26.4	26.4	NAP	26.5	26.5
Fuel Pump Inlet Temperature	°R	37.9	NAP	37.9	37.9	NAP	38.0	37.9
LOX Pump Inlet Pressure — Total	psia	29.0	NAP	41.4	41.4	NAP	40.8	40.9
LOX Pump Inlet Temperature	°R	170.7	NAP	175.3	175.2	NAP	175.3	175.3
Chamber Pressure (Injector Face Static)	psia	431.6	NAP	430.2	430.6	NAP	432.4	432.4

Table V-7. *Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)*

Item	Units	Engine No. XR103-2						
Actual Mixture Ratio		5.866	NAP	5.919	5.894	NAP	5.885	5.903
Trim Mixture Ratio		—	—	—	—	—	—	—
Percent of Trim Mixture Ratio	%	—	—	—	—	—	—	—
Thrust at 200,000 ft	lbs	15,258	NAP	15,331	15,338	NAP	15,358	15,374
Trim Thrust at 20,000 ft	lbs	14,962	NAP	14,977	14,970	NAP	14,967	14,972
Percent of Trim Thrust	%	1.98	NAP	2.36	2.45	NAP	2.61	2.68
Specific Impulse	sec	436.3	NAP	435.5	435.4	NAP	436.6	436.8
Specific Impulse at r = 6.0	sec	435.2	NAP	434.8	434.5	NAP	—	—
Specific Impulse Efficiency at r = 60	%	94.54	NAP	94.68	94.60	NAP	—	—
Characteristic Vel Efficiency at r = 6.0 (Inj Face Pc)	%	97.59	NAP	96.96	96.89	NAP	—	—
Thrust Coeff Efficiency at r = 6.0 (Inj Face Pc)	%	96.87	NAP	97.65	97.63	NAP	—	—
Steady State LOX Pump Speed	rpm	12,300	NAP	12,245	12,257	NAP	12,262	12,262
Coolant Outlet Temperature - Steady State Fuel Turbine Inlet Temperature	°R	441.6	NAP	444.0	441.3	NAP	443.8	444.7
$\Delta T/\Delta T'$ at r = 6.0 (Corrected)	%	102.7	NAP	104.2	104.0	NAP	—	—
Hydrogen Leakage Total/Gearbox 0.15 max	lbs/sec	0.072/0.054	NAP	0.068/0.052	0.068/0.051	NAP	0.059/0.044	0.058/0.044
Chamber Pressure	psia	—	—	—	—	—	—	—
Mixture Ratio		—	—	—	—	—	—	—
Thrust Control Body Pressure		—	—	—	—	—	—	—
Chamber Pressure Ratio (Inj Face/Igniter Tap)		0.9914	NAP	0.9894	0.9885	NAP	0.9893	0.9895
Oxidizer Flow Control Valve "K" Factor/Propellant Utilization Valve Angle		6.36/−7.32	NAP	6.16/−8.61	6.19/−8.62	NAP	5.98/−8.61	6.18/−8.68
Fuel Injector Effective Area (Inj Face Pc)		2.389	NAP	2.393	2.398	NAP	2.413	2.414
LOX Injector Effective Area (Inj Face Pc)		0.739	NAP	0.734	0.727	NAP	0.738	0.736
Fuel Tank/Pressurization Bleed Flow at r = 5.0	ft/sec	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Stability (Pc Amplitude)	psia	NAV	NAV	NAV	NAV	NAV	NAV	NAV
Thrust Tare Prerun/Postrun	lbs	−264/NAP	NAP	−252/NAP	−252/NAP	NAP	−263/NAP	−263/NAP
Helium Consumption 0.05 max	lbs	NAP	NAP	NAP	NAP	NAP	NAP	NAP
Shutdown Impulse (at 200,000 ft) Uncorrected	lbs/sec	1417	NAP	1223	1183	NAP	1212	1219
Shutdown Impulse (at 200,000 ft) Corrected	lbs/sec	1318	NAP	1288	1261	NAP	1275	1285
Decel. Time (Meas at S.L. Cond)	sec	0.143	NAP	—	0.131	NAP	0.141	0.134
Valve Helium Supply Pressure 440-500	psia	471.4	471.2	472.0	472.0	470.8	475.7	475.9
Solenoid Voltage 20-30	volts	25.6	24.8	26.9	26.9	26.9	26.7	27.0
Main Fuel Shutoff Valve Delta Closing Time	sec	0.069	0.068	0.054	0.054	0.055	0.053	0.053
Oxidizer Inlet Valve Delta Closing Time	sec	0.275	0.270	0.245	0.245	0.237	0.248	0.244

Table V-7. *Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)*

Engine No. XR103-2

Item		Units						
Stand			E-6	E-6	E-6	E-6	E-6	E-6
Run No.			23.01	24.01	25.01	26.01	27.01	28.01
Date			1-10-86	1-13-86	1-14-86	1-14-86	1-15-86	1-15-86
Hot Time		sec	6.2	510.1	450.9	350.8	476.5	350.1
Total Hot Time		sec	3555.0	4065.1	4516.0	4866.8	5343.3	5693.4
Fuel Pump Inlet Pressure — Static		psia	27.6	27.6	27.4	27.6	27.6	27.4
Fuel Pump Inlet Temperature		°R	38.9	38.8	38.7	38.9	38.7	38.9
LOX Pump Inlet Pressure - Static		psia	44.0	44.2	44.2	44.1	44.1	44.5
LOX Pump Inlet Temperature		°R	175.9	175.9	175.8	175.8	175.7	175.6
Oxidizer Pump Housing Temperature Prestart/Start		°R	202/194	438/181	443/183	453/183	438/182	461/182
Fuel Pump Housing Temperature Prestart/Start		°R	110/76	447/84	440/83	446/83	428/82	460/83
Fuel Turbine Inlet Temperature Prestart/Start		°R	412/414	473/469	487/485	496/491	477/540	508/504
Accel. Time (To 90% Thrust) Uncorrected		sec	1.523	1.772	1.797	1.707	1.731	1.749
Accel. Time (To 90% Thrust) Corrected		sec	1.558	1.820	1.795	1.755	1.792	1.788
Starting Impulse (To 2 sec) Uncorrected		lbs-sec	24,521	20,761	20,284	21,534	21,274	20,959
Starting Impulse (To 2 sec) Corrected		lbs-sec	23,976	20,047	20,313	20,812	20,363	20,379
Peak Transient Thrust	17740 max	lbs	15,189	15,168	15,361	15,195	15,180	15,245
Percent Thrust Overshoot		%	1.261	1.117	2.41	1.302	1.201	1.64
Maximum Rate of Thrust Increase	Nap/250	lbs/milli-sec	730/137	1016/115	960/90	1225/70	1008/94	1183/87
Maximum Start Oxidizer Flow	40.5 max	lbs/sec	30.0	30.4	30.4	30.3	30.2	30.5
Maximum Start Fuel Flow	7.1 max	lbs/sec	4.9	4.7	4.8	4.8	4.74	4.64
External Power at Maximum Demand	30/8.5 max	Volts/Amps	23.9/6.0	24.1/6.1	25.3/6.3	29.6/6.6	23.2/6.2	24.1/6.0
Fuel Pump Discharge Pressure and Interstage Cooldown Valve Start to Close		psia	NAV	NAV	NAV	NAV	NAV	NAV
Oxidizer Flow Control Valve Cracking Pressure		psid	75	79	80	80	79	85
Sparks to Light			1	1	2	1	1	1
Fuel Pump Inlet Pressure - Total		psia	NAP	25.6	25.6	25.6	25.8	25.7
Fuel Pump Inlet Temperature		°R	NAP	37.9	37.9	37.9	38.0	38.0
LOX Pump Inlet Pressure - Total		psia	NAP	40.8	41.2	41.4	41.4	41.4
LOX Pump Inlet Temperature		°R	NAP	175.3	175.1	175.1	175.3	175.1
Chamber Pressure (Injector Face Static)		psia	NAP	433.6	432.8	432.5	428.3	431.4

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Table V-7. Pratt & Whitney Aircraft RL10A-3-3B Engine Performance Summary (Continued)

Engine No. XR103-2

Item		Units						
Actual Mixture Ratio			NAP	5.755	5.862	5.911	6.746	6.012
Trim Mixture Ratio			NAP	—	—	—	—	—
Percent of Trim Mixture Ratio		%	NAP	—	—	—	—	—
Thrust at 200,000 ft.		lbs	NAP	15,350	15,391	15,317	15,440	15,416
Trim Thrust at 200,000 ft		lbs	NAP	14,928	14,960	14,975	15,169	15,003
Percent of Trim Thrust		%	NAP	2.82	2.88	2.287	1.79	2.75
Specific Impulse		sec	NAP	436.9	436.2	434.2	427.7	436.4
Specific Impulse at r −6.0		sec	NAP	435.2	435.4	433.4	435.9	436.3
Specific Impulse Efficiency at r −6.0		%	NAP	94.70	94.78	94.35	94.82	94.92
Characteristic Vel. Efficiency at r −4.0 (Inj. Face Pc)		%	NAP	97.34	97.26	97.21	97.38	97.24
Thrust Coeff. Efficiency at r −6.0 (Inj. Face Pc)		%	NAP	97.29	97.45	97.06	97.37	97.61
Steady State LOX Pump Speed		rpm	NAP	12,350	12,298	12,268	11,839	12,198
Coolant Outlet Temperature - Steady State Fuel Turbine Inlet Temperature		°R	NAP	437.8	444.5	441.6	481.3	450.1
ΔT/ΔT' at r −6.0 (Corrected)		%	NAP	104.1	104.3	103.3	103.4	104.0
Hydrogen Leakage Total/Gearbox	0.15 max	lbs/sec	NAP	0.071/0.057	0.070/0.056	0.070/0.058	0.057/0.043	0.060/0.047
Chamber Pressure		psia	NAP	—	—	—	—	—
Mixture Ratio			NAP	—	—	—	—	—
Thrust Control Body Pressure			NAP	—	—	—	—	—
Chamber Pressure Ratio (Inj. Face/Igniter Tap)			NAP	0.9914	0.9899	0.9904	0.9904	0.9892
Oxidizer Flow Control Valve "K" Factor/Propellant Utilization Valve Angle			NAP	6.75/−1.11	6.06/−6.51	6.28/−8.51	2.42/−70.2	5.67/−15.2
Fuel Injector Effective Area (Inj. Face Pc)			NAP	2.439	2.470	2.432	2.449	2.452
Oxidizer Injector Effective Area (Inj. Face Pc)			NAP	0.746	0.740	0.744	0.759	0.727
Fuel Tank Pressurization Bleed Flow at r = 6.0		ft/sec	NAP	0.109	0.111	NAP	NAP	NAP
Stability (Pc Amplitude)		±psia	NAP	NAV	NAV	NAV	NAV	NAV
Thrust Tare Prerun/Postrun		lbs	NAP	−263/−224	−255/−212	−279/−235	−273/−216	−239/−184
Helium Consumption	0.5 max	lbs	NAP	NAP	NAP	NAP	NAP	NAP
Shutdown Impulse (At 200,000 ft.) Uncorrected		lbs-sec	NAP	1179	1209	1212	1195	1183
Shutdown Impulse (At 200,000 ft.) Corrected		lbs-sec	NAP	1341	1223	1288	1276	1276
Decel. Time (Meas. at S.L. Cond.)		sec	NAP	0.137	0.133	0.134	0.131	0.132
Valve Helium Supply Pressure	440 - 500	psia	474.8	424.2	514.1	472.4	471.7	474.4
Solenoid Voltage	20 - 30	Volts	26.7	27.3	27.4	31.0	26.5	26.7
Main Fuel Shutoff Valve Delta Closing Time		sec	0.054	0.052	0.055	0.053	0.054	0.053
Oxidizer Inlet Valve Delta Closing Time		sec	0.252	0.221	0.245	0.253	0.232	0.240

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5.2 Effects on Transients

5.2.1 Effect of Solenoid Voltage

To determine the effect of solenoid voltage on the start and shutdown transients, runs were made at maximum and minimum voltage and compared to a nominal start and shutdown. Minimum voltage (18.3 vdc) was used in Run 4.01 and maximum voltage (31.0 vdc) in Run 26.01. Run 5.01 was a nominal run.

The start transients for each case are compared to the nominal start transient in Figures V-21 and V-22, and Table V-8 shows the solenoid voltage effect on valve actuation. With minimum voltage, valve actuation times increased 51 msec, ignition occurred 85 msec later vs nominal and the igniter spark interval increased 32 msec. With maximum voltage, valve actuation time decreased 9 msec and ignition occurred 8 msec sooner vs nominal. For each case, start and acceleration are within limits stated in RL10A-3-3B Specification No. 2295.

The solenoid voltage effect on valve actuation and deceleration time are presented in Table V-9, showing no significant change relative to nominal. Figure V-23 shows the voltage effect on shutdown impulse and the preliminary specification estimate. Also, the specification estimate as provided in the RL10A-3-3B Specification No. 2295 is shown.

Since engine ignition, acceleration and deceleration are acceptable at the solenoid voltage extremes, a solenoid voltage range from 20 to 30 vdc was provided in RL10A-3-3B Specification No. 2295.

5.2.2 Effect of Solenoid/Chamber Temperature

To determine the effect of solenoid valve and thrust chamber temperature on start and shutdown transients, runs were made at extreme temperature conditions and compared to a nominal run. Run 15.01 operated with precooled solenoids, Run 19.01 with a cooled chamber, and Run 13.01 with preheated solenoids/chamber. These runs have been compared to Run 5.01, a nominal run. Table V-10 lists the solenoid and/or chamber temperatures for each run. Additionally, a rapid relight procedure was used to define the effects of minimum chamber temperature since it closely simulates minimum chamber temperatures experienced during operation in space.

The start transients of Runs 19.01, 13.01 and 5.01 are compared in Figures V-24 and V-25. In general, engine acceleration will not be affected by solenoid temperatures, so Run 15.01 is not used for start transient comparisons. Table V-8 shows solenoid/chamber temperature effects on valve actuation. Notice the acceleration of the runs shown in Figures V-24 and V-25; Run 19.01 (cool chamber) accelerates quickest followed by Run 5.01 (nominal), and then Run 13.01 (warm chamber). However, this result is unexpected since engine acceleration should vary inversely with chamber temperature. The faster acceleration of the cool chamber compared to nominal and the warm chamber is due to the prestart duration of rapid relight runs (cool chamber). The prestart duration of Run 19.01 (relight test) is 5.0/8.0 sec, Fuel/LOX compared to 40.0/220.0 sec for Runs 5.01 and 13.01. Table V-7 shows the rapid relight tests consistently accelerate faster than the nominal and warm chamber run. The slower acceleration of Run 13.01 compared to 5.01 has been traced to pump cavitation with additional effects from ignition and valve actuation. Pump cavitation for Run 13.01 is compared relative to Run 5.01 in Figure V-26, and shows fuel side cavitation for Run 13.01. Table V-6 lists the pump housing temperatures for each run, which is 8°R higher on the fuel side for Run 13.01. In addition, the main fuel valve opened 8 msec later for Run 13.01 relative to nominal and ignition occurred 25 msec later, as presented in Table V-8.

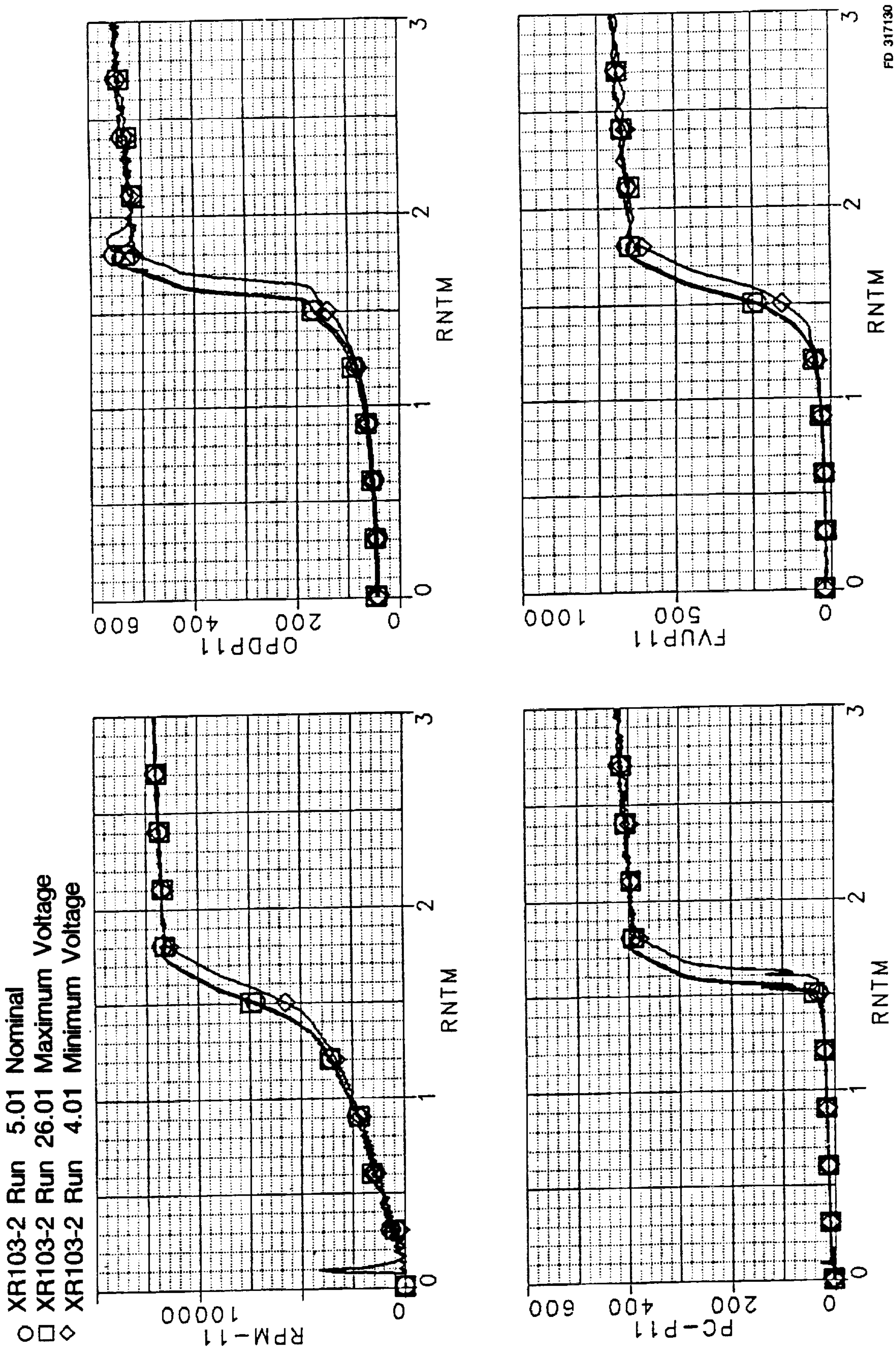

Figure V-21. Solenoid Voltage Effect on Start Transient — RNTM

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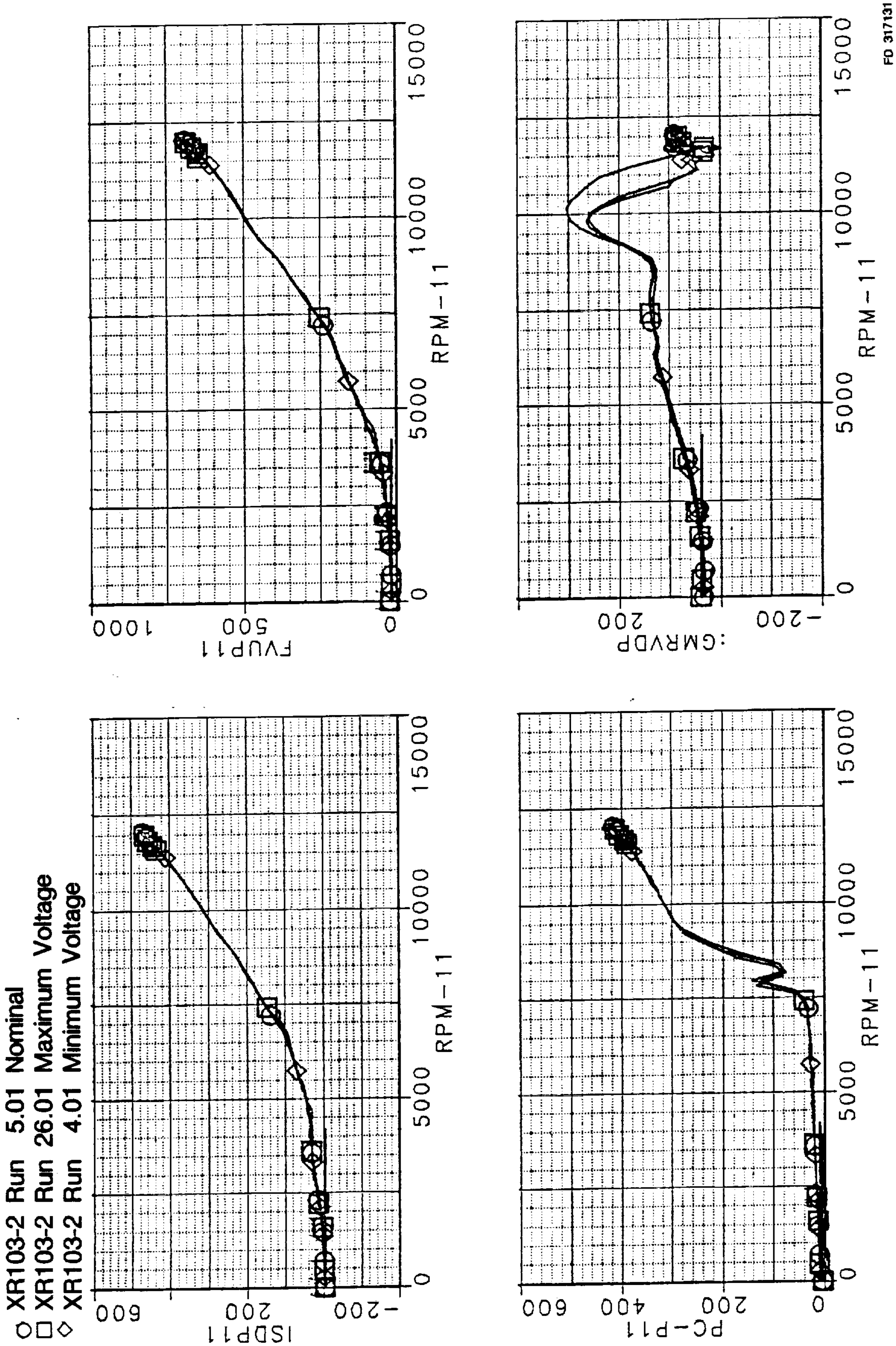

Figure V-22. Solenoid Voltage Effect on Start Transient — RPM-11

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Table V-8. Engine Conditioning Effects on Valve Actuation at Start

Run No.	Condition	SV-8 Open (sec)	SV-10 Close (sec)	SV-6 Close (sec)	Ignition; (No. Sparks) (sec): (lb)	Igniter Interval (sec)
5.01	Pre-Qual Nominal	0.074	1.514	0.074	0.086:(1)	0.027
27.01	Post-Qual Nominal	0.075	1.533	0.076	0.086:(1)	0.028
4.01	Minimum Voltage	0.123	1.592	0.126	0.071:(1)	0.041
26.01	Maximum Voltage	0.064	1.544	0.066	0.078:(1)	0.025
15.01	Minimum Temp	0.070	1.669	0.070	0.087:(1)	0.027
13.01	Maximum Temp	0.082	1.730	0.072	0.111:(1)	0.028
24.01	Minimum Helium Press	0.066	1.595	0.075	0.086:(1)	0.027
25.01	Maximum Helium Press	0.076	1.614	0.076	0.107:(1)	0.026

Note: SV-6 = Fuel Pump Discharge Cooldown Valve
SV-8 = Main Fuel Valve
SV-10 = Fuel Pump Interstage Cooldown Valve

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Table V-9. Engine Conditioning Effects on Valve Actuation at Shutdown

Run No.	Condition	SV-8 Close (sec)	SV-4 Close (sec)	Deceleration Time (sec)
5.01	Pre-Qual Nominal	0.050	0.250	0.144
27.01	Post-Qual Nominal	0.054	0.232	0.131
4.01	Minimum Voltage	0.052	0.211	0.141
26.01	Maximum Voltage	0.053	0.235	0.134
15.01	Minimum Temp	0.070	0.280	0.146
13.01	Maximum Temp	0.047	0.243	0.128
24.01	Minimum Helium Press	0.052	0.221	0.137
25.01	Maximum Helium Press	0.055	0.245	0.133

Note: SV-4 = LOX Inlet Valve
SV-8 = Main Fuel Valve

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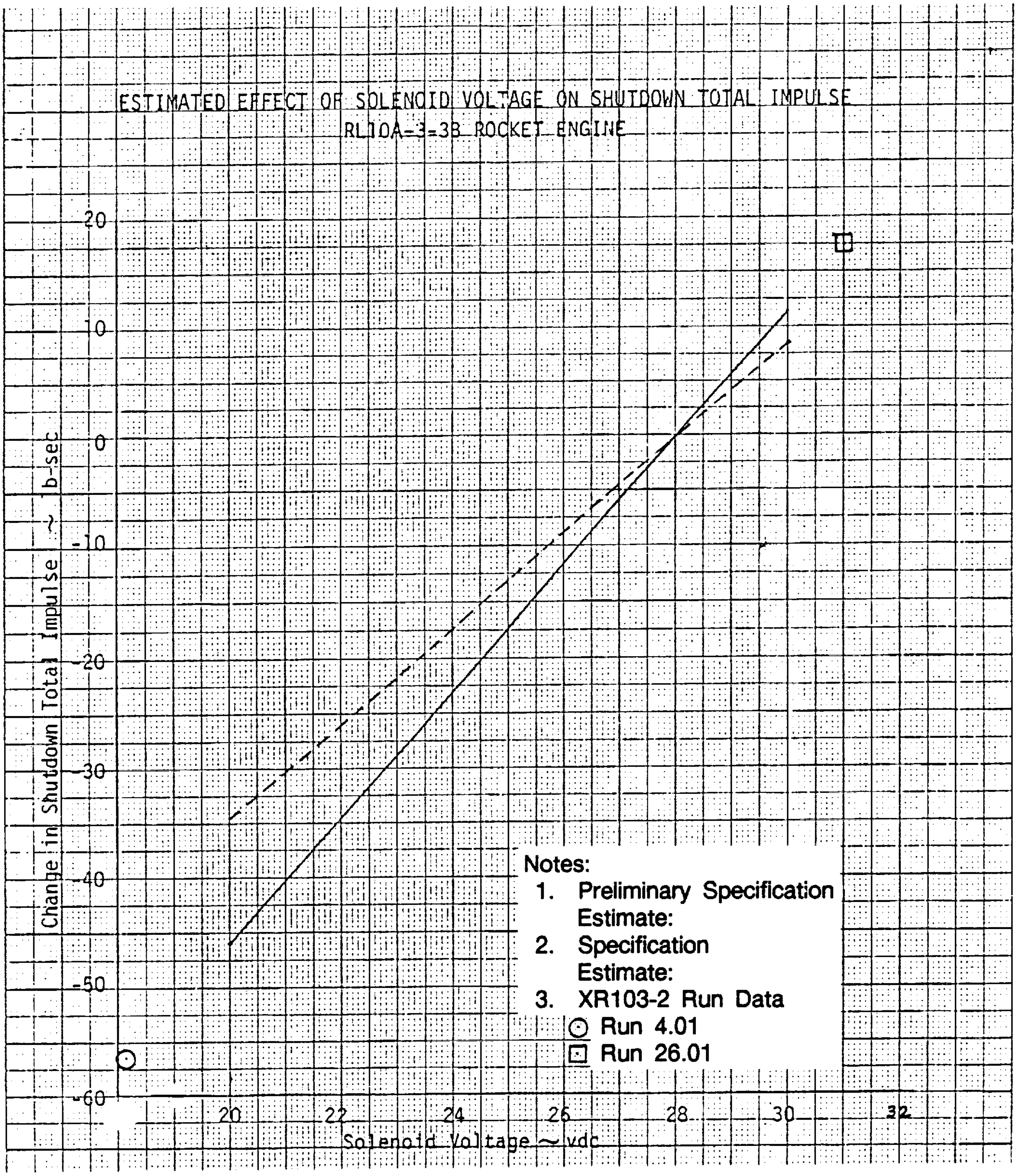

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Figure V-23. Estimated Effect of Solenoid Voltage on Shutdown Total Impulse

Table V-10. Solenoid/Chamber Temperatures For Various Runs at Start and Prestart

Run No.	Type	Prestart Solenoid/Chamber	Start Solenoid/Chamber
5.01	Nominal	555/553°R	554/229°R
13.01	Hot S/C	670/649°R	664/423°R
15.01	Cool S	335/NA°R	360/NA°R
19.01	Cool C	NA/452°R	NA/444°R

NA : Not Applicable
S : Solenoid
C : Chamber

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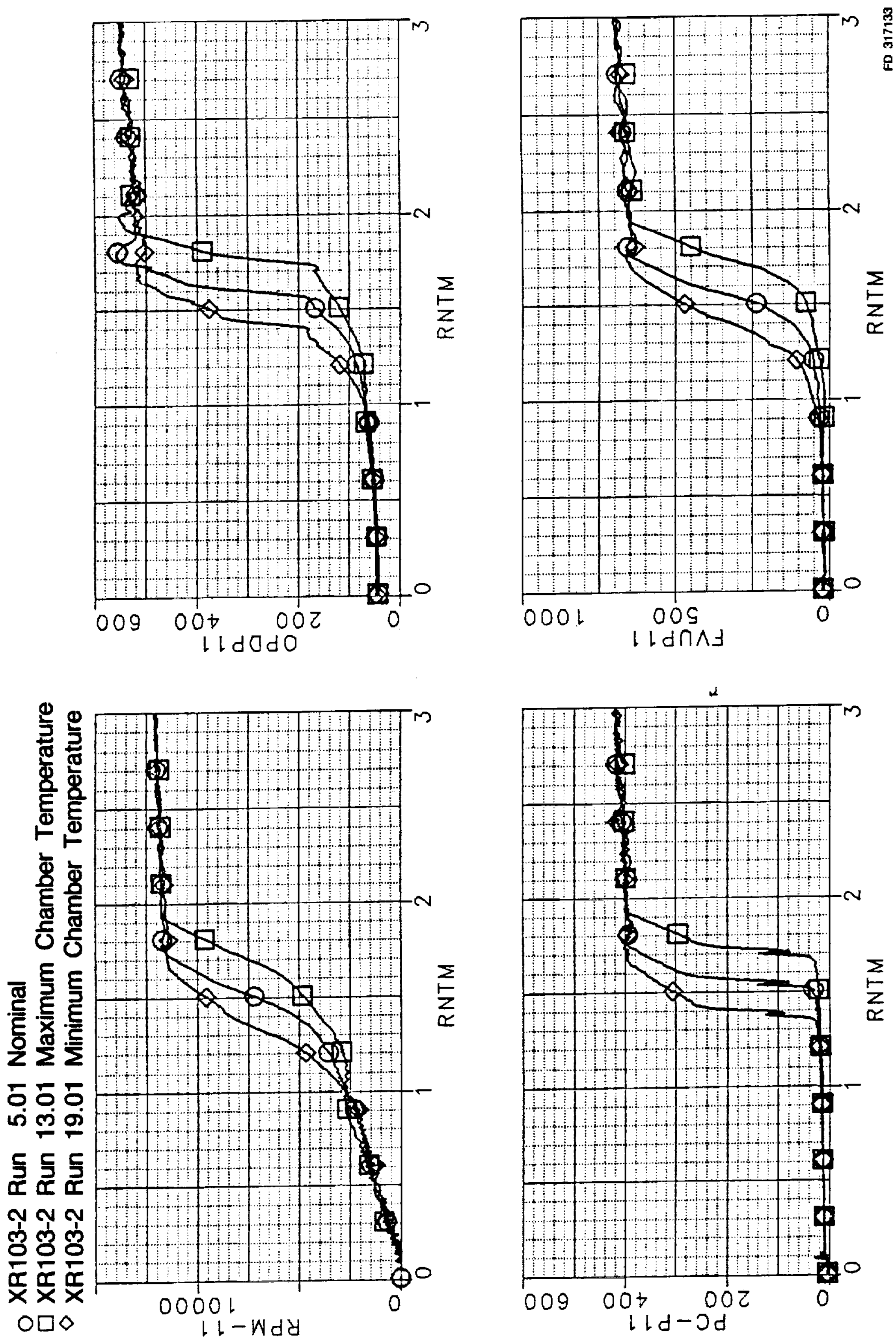

Figure V-24. Chamber Temperature Effect on Start Transient — RNTM

9046M

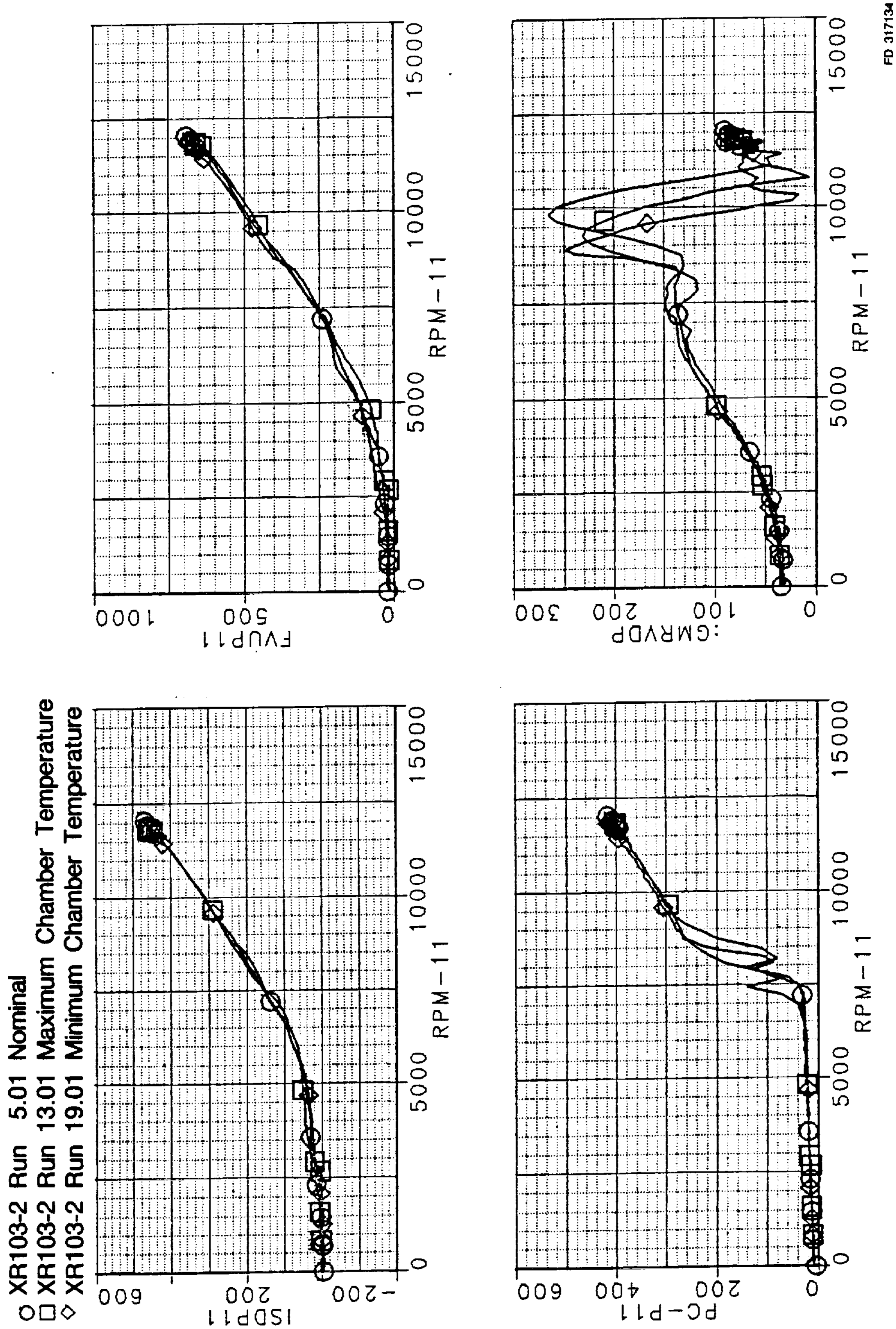

Figure V-25. Chamber Temperature Effect on Start Transient — RPM-11

9046M

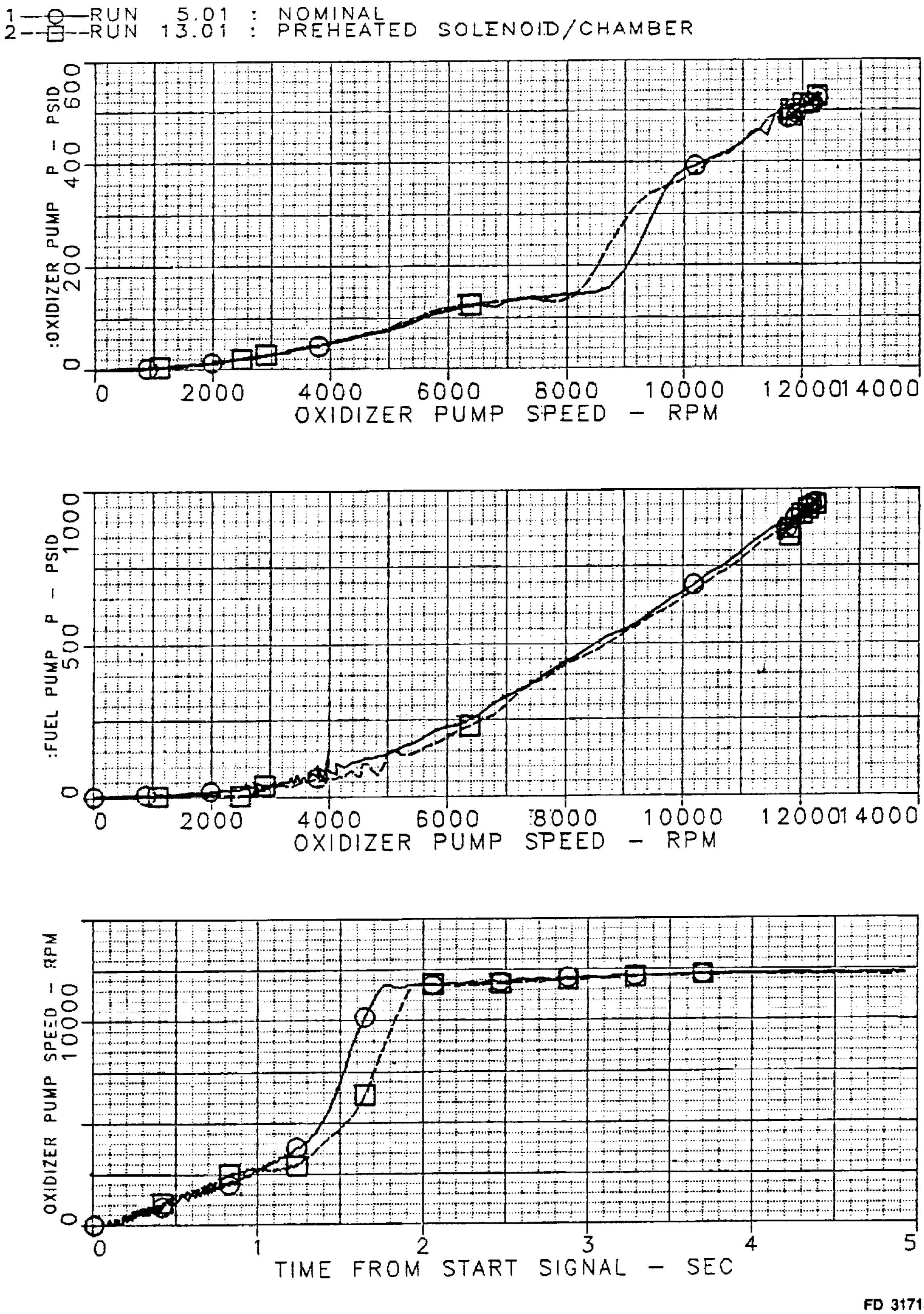

Figure V-26. Turbopump Cavitation — Warm Solenoid/Chamber Temperature

9046M

The solenoid temperature effects on valve actuation at shutdown and deceleration time are presented in Table V-9, which shows no significant change from nominal. Figure V-27 shows solenoid temperature effect on shutdown impulse and the preliminary specification estimate. Also, Figure V-27 shows specification estimate determined and provided in the RL10A-3-3B specification.

Engine ignition, acceleration and deceleration are acceptable for the solenoid/chamber temperature extremes at prestart of (335-670°R) solenoids, (452-650°R) chamber and at start of (360-664°F) solenoids, (229-444°R) chamber. These temperature ranges have been used to define the RL10A-3-3B engine operating temperature range of 250/600°R provided to the RL10A-3-3B specification.

5.2.3 *Effect of Valve Helium Supply Pressure*

To determine the effect of valve helium supply pressure on start and shutdown transients, runs were made at minimum and maximum helium supply pressures and compared to a nominal run. Run 24.01 operated with minimum supply pressure (424.4 psia), Run 25.01 operated with maximum supply pressure (514.1 psia), and Run 5.01 was a nominal run.

The start transients for each case are compared to the nominal start transient in Figures V-28 and V-29, and Table V-8 shows the helium supply pressure effect on valve actuation. Valve actuation and ignition time varied slightly compared with the nominal run. The engine start and acceleration are within limits presented in RL10A-3-3B Specification No. 2295 for each case.

The helium supply pressure effect on valve actuation and deceleration is presented in Table V-9. Minimum supply pressure decreased valve actuation and increased deceleration time but maximum supply pressure exerted no effect. Figure V-30 shows helium supply pressure effect on shutdown impulse and the specification estimate for this effect.

Since engine start, acceleration and deceleration are acceptable at the valve helium supply pressure extremes, a supply pressure range of 440 to 500 psia has been provided for RL10A-3-3B Specification No. 2295.

5.2.4 *Effect of Mixture Ratio*

To determine the effect of mixture ratio on the shutdown transient, runs were shut down from various mixture ratios and the influence on engine performance determined. Runs 4.01 and 5.01 were shut down from low mixture ratios, however these runs experienced additional engine effects. Run 4.01 was shut down from low mixture ratio and low solenoid voltage, and Run 5.01 was shut down from low mixture ratio and a high solenoid temperature. These runs have been excluded from this analysis. Run 24.01 was shut down from a low mixture ratio of 5.755, and Run 27.01 was shut down from a high mixture ratio of 6.746. The influence of shutdown mixture ratio on performance is shown in the curve of Figure V-31. The qualification testing verified the prequalification estimate, therefore this estimate has been submitted for the RL10A-3-3B specification.

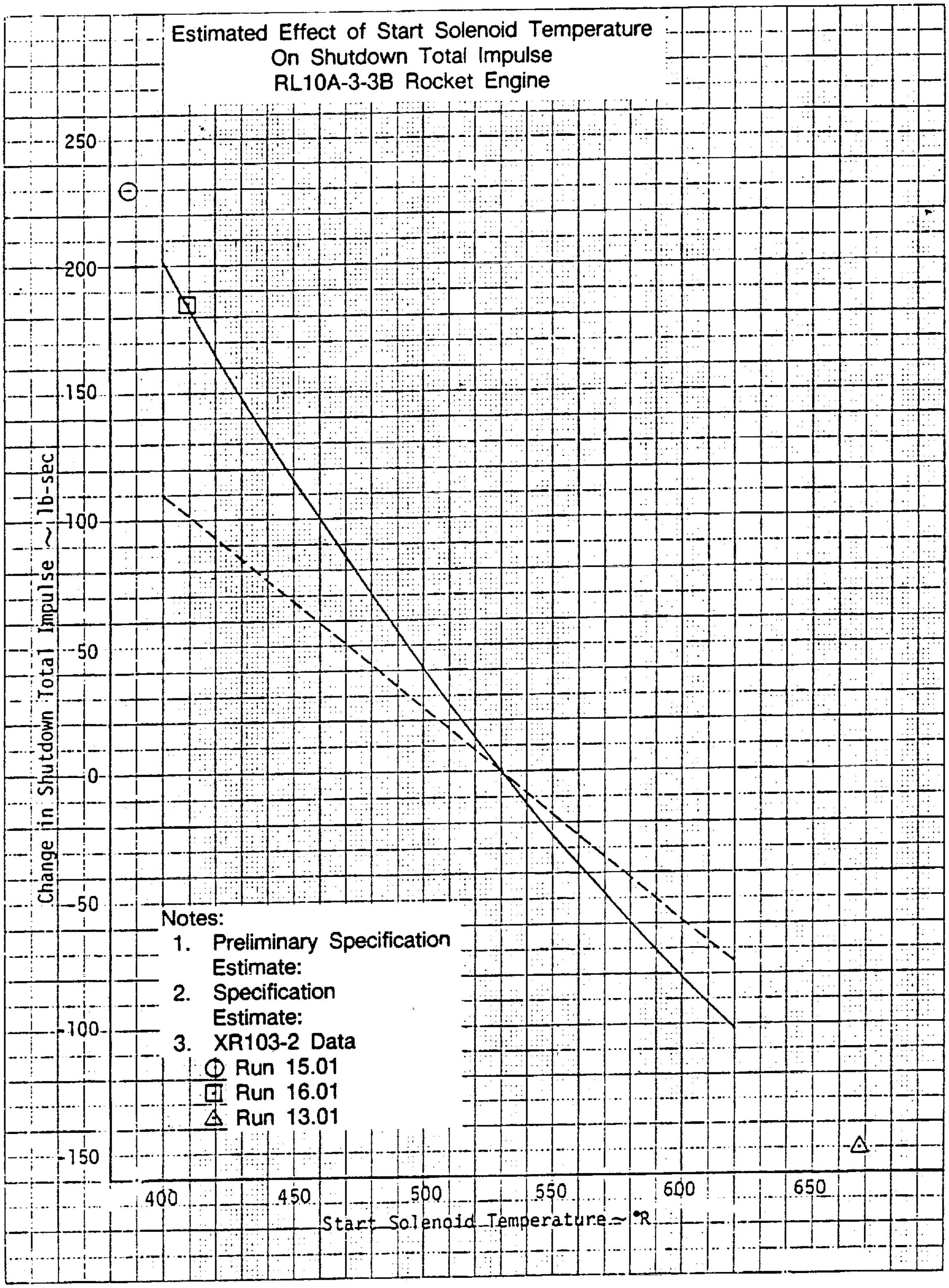

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Figure V-27. Estimated Effect of Start Solenoid Temperature on Shutdown Total Impulse

9046M

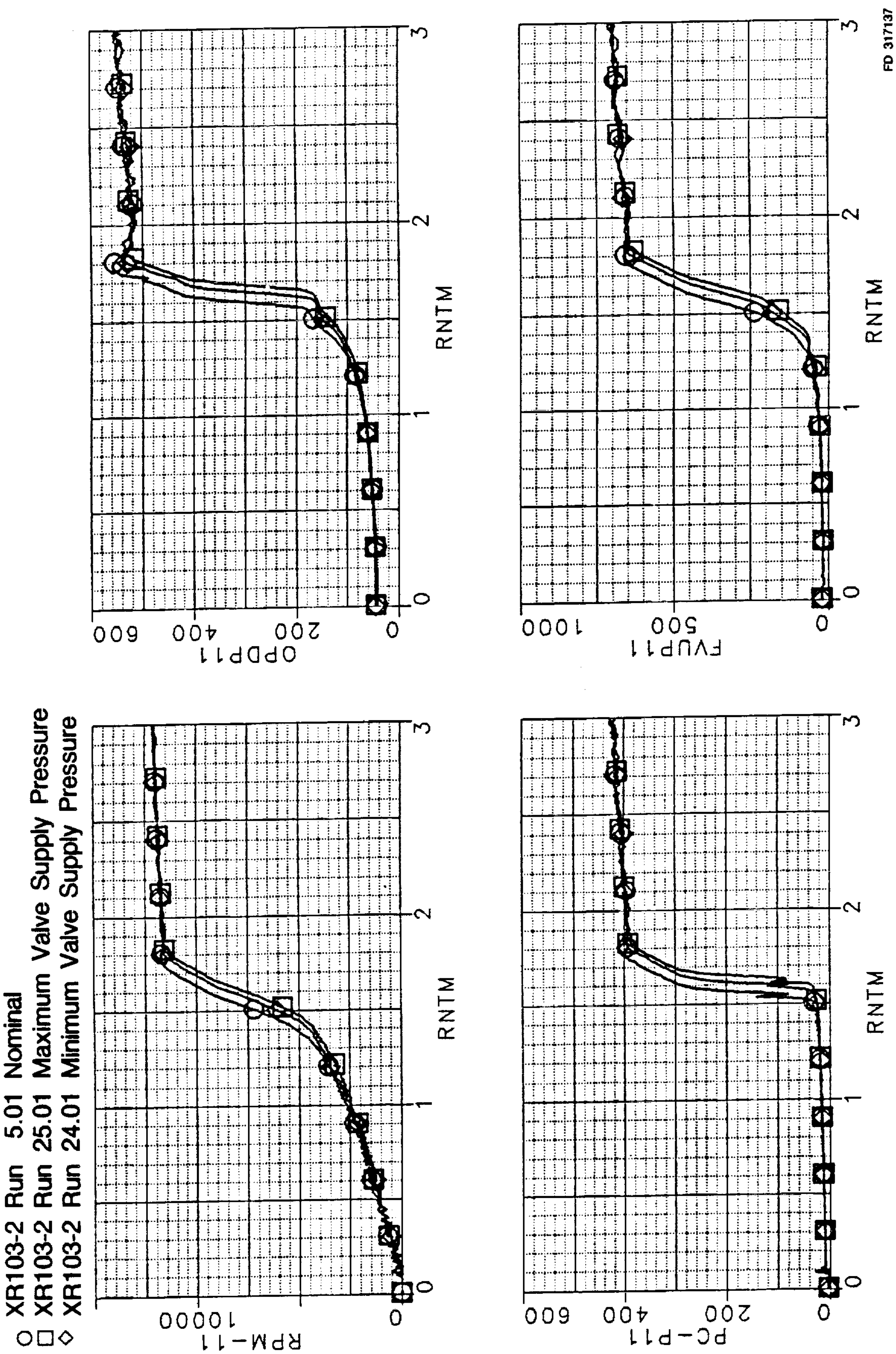

Figure V-28. Valve Helium Supply Pressure Effect on Start Transient — RNTM

9046M

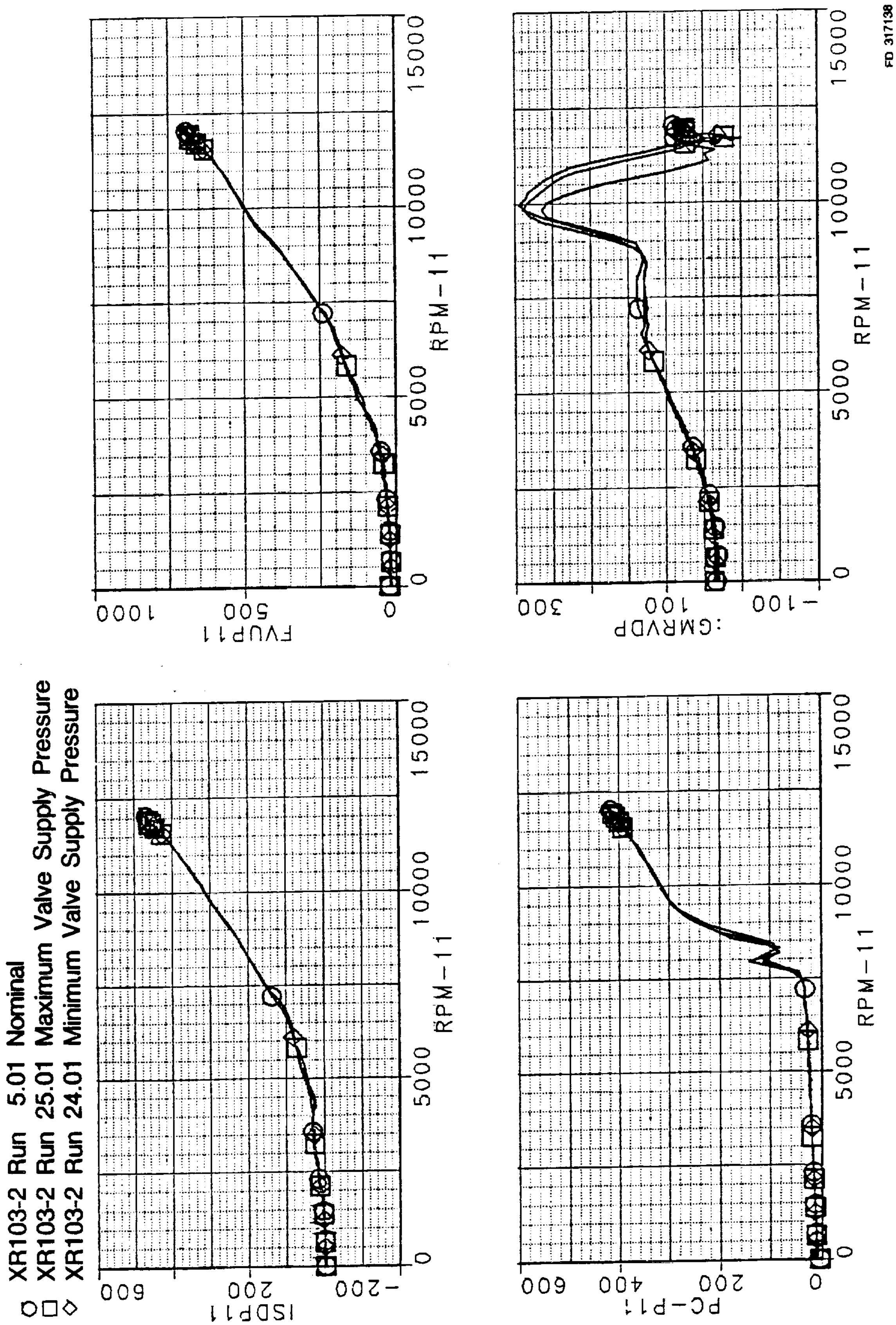

Figure V-29. Valve Helium Supply Pressure Effect on Start Transient — RPM-11

9046M

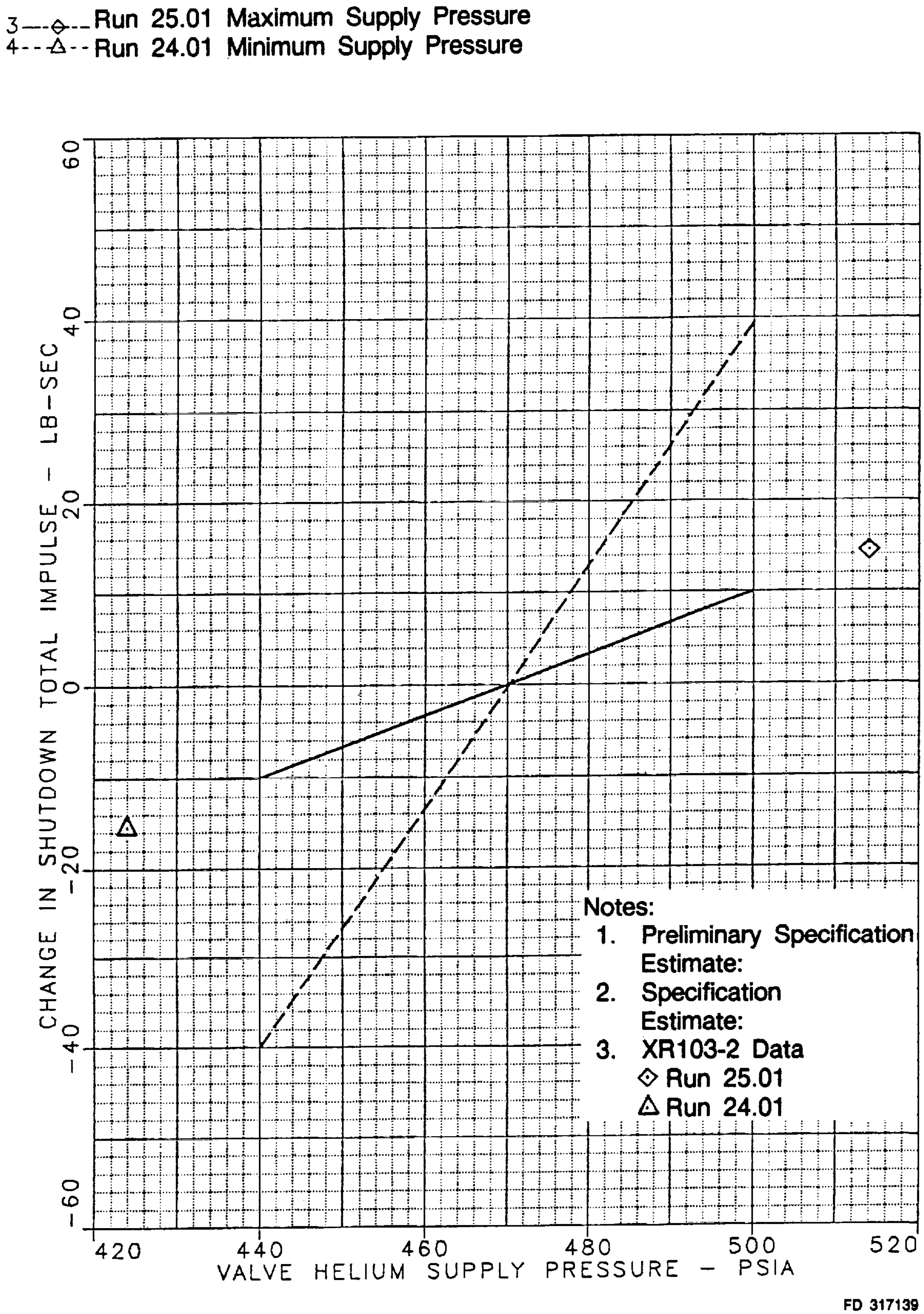

Figure V-30. Effect of Valve Helium Supply Pressure on Shutdown Total Impulse

9046M

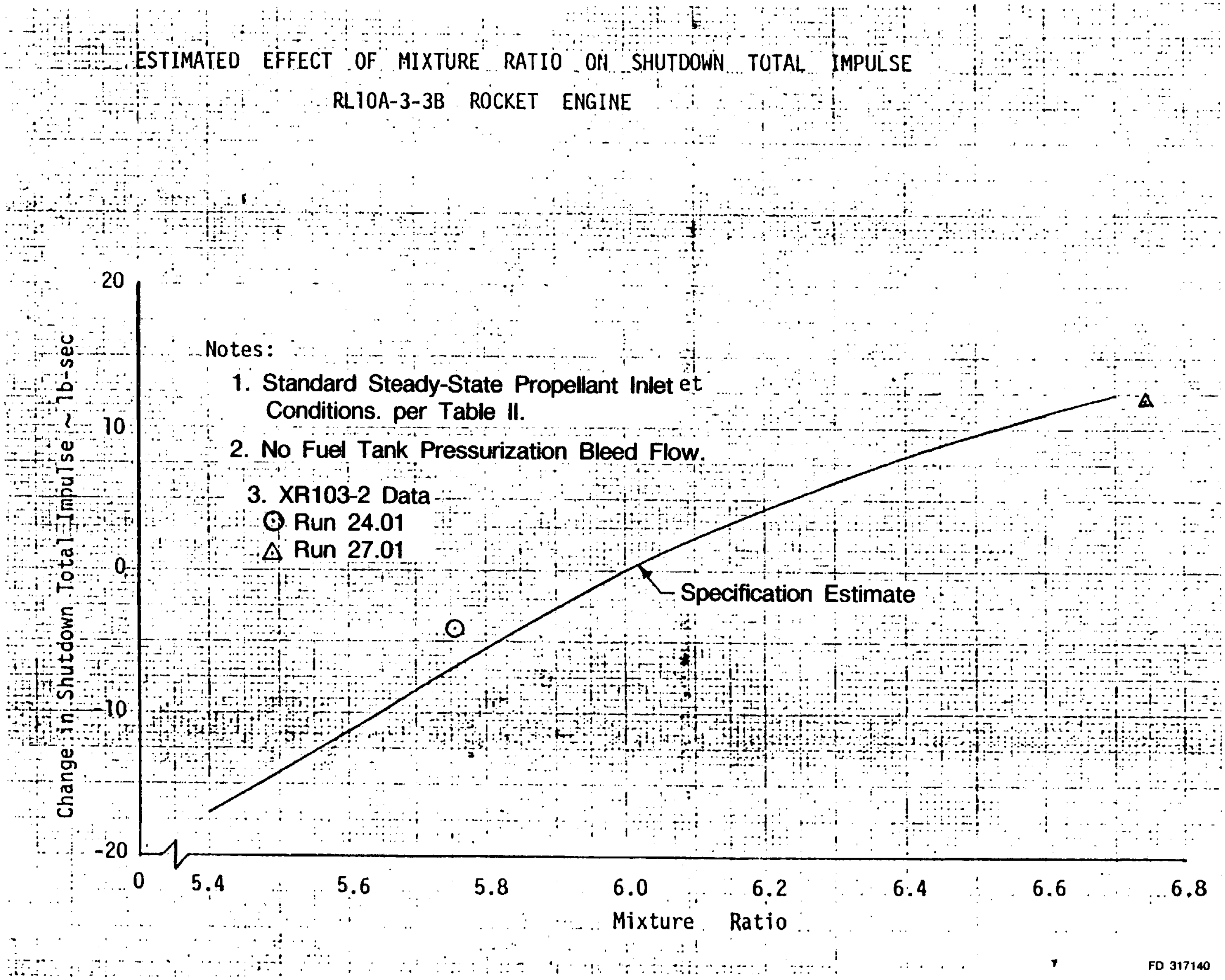

Figure V-31. Estimated Effect of Mixture Ratio on Shutdown Total Impulse

5.2.5 Effect of Inlet Condition Variation from Nominal

The effect of inlet condition variation from nominal during the start transient was observed in many runs during qualification testing. Table V-11 presents the inlet conditions effect on engine acceleration as compared to the nominal acceleration. Figures V-32 and V-33 show the inlet conditions tested, Figures V-34 to V-41 present start transients of these runs contrasted with a nominal transient. Notice that the start inlet conditions lie beyond the start operating boxes of Figures V-32 and V-33 to define these envelopes. Since engine start performance is acceptable as seen in Figures V-34 to V-41, the inlet start boxes defined in Figures V-32 and V-33 have been submitted for the RL10A-3-3B specification.

Table V-11. *RL10A-3-3B Start Box Limits Inlet Condition Variation Effect on Acceleration Time*

		Engine XR103-2		
	Run	NPSP Condition		Change in
Run No.	Type	Fuel	Oxidizer	Acceleration Time
7.01	1st burn	Min	Max	0.623
8.01	relight	Min	Max	0.146
9.01	1st burn	Max	Max	−0.078
10.01	relight	Max	Max	−0.233
11.01	1st burn	Max	Min	−0.286
12.01	relight	Max	Min	−0.392
15.01	1st burn	Min	Min	0.118
16.01	relight	Min	Min	−0.140

Note: Times are compared to nominal RL10A-3-3B acceleration time of 1.809 sec, as submitted for Specification 2295. Positive denotes a slower acceleration while negative denotes a faster acceleration.

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5.2.6 Cooldown Limit Tests

Four first-burn tests were run with extreme conditions on the inlet start boxes and prestart times to complete the cooldown limit tests. The extreme Net Positive Suction Pressure (NPSP) conditions (Max or Min), change in acceleration time and corresponding runs are presented in Table V-11. Additionally, each test was followed by a rapid relight two minutes after shutdown, with the same starting inlet conditions listed in Table V-7. Figures V-34 to V-41 compare the start transients for the first-burn runs to nominal, and Figures V-42 to V-49 compare relight start transients to nominal. Figures V-55 to V-58 show no indication of cavitation during engine acceleration for these runs, displaying acceptable engine start capability. Inlet start boxes defined in Figures V-34 and V-35, and related minimum prestart times determined from previous testing, Figure V-54, have been provided for the RL10A-3-3B specification.

5.3 Effects on Steady State

5.3.1 Minimum Steady State NPSP

To determine the effect of minimum pump inlet NPSP during steady state operation, runs 18.01 and 24.01 were conducted at minimum fuel pump inlet NPSP (3.0 psid) and minimum oxidizer pump inlet NPSP (5.2 psid) during steady state, respectively. The performance for each pump was within run-to-run variation, indicating no cavitation. Pump performance is shown in Figures V-59 and V-60. Steady state operation was not affected due to low inlet NPSP levels, verifying minimum NPSP levels of 3.0 psid fuel and 5.2 psid oxidizer. These have been provided for RL10A-3-3B Specification No. 2295.

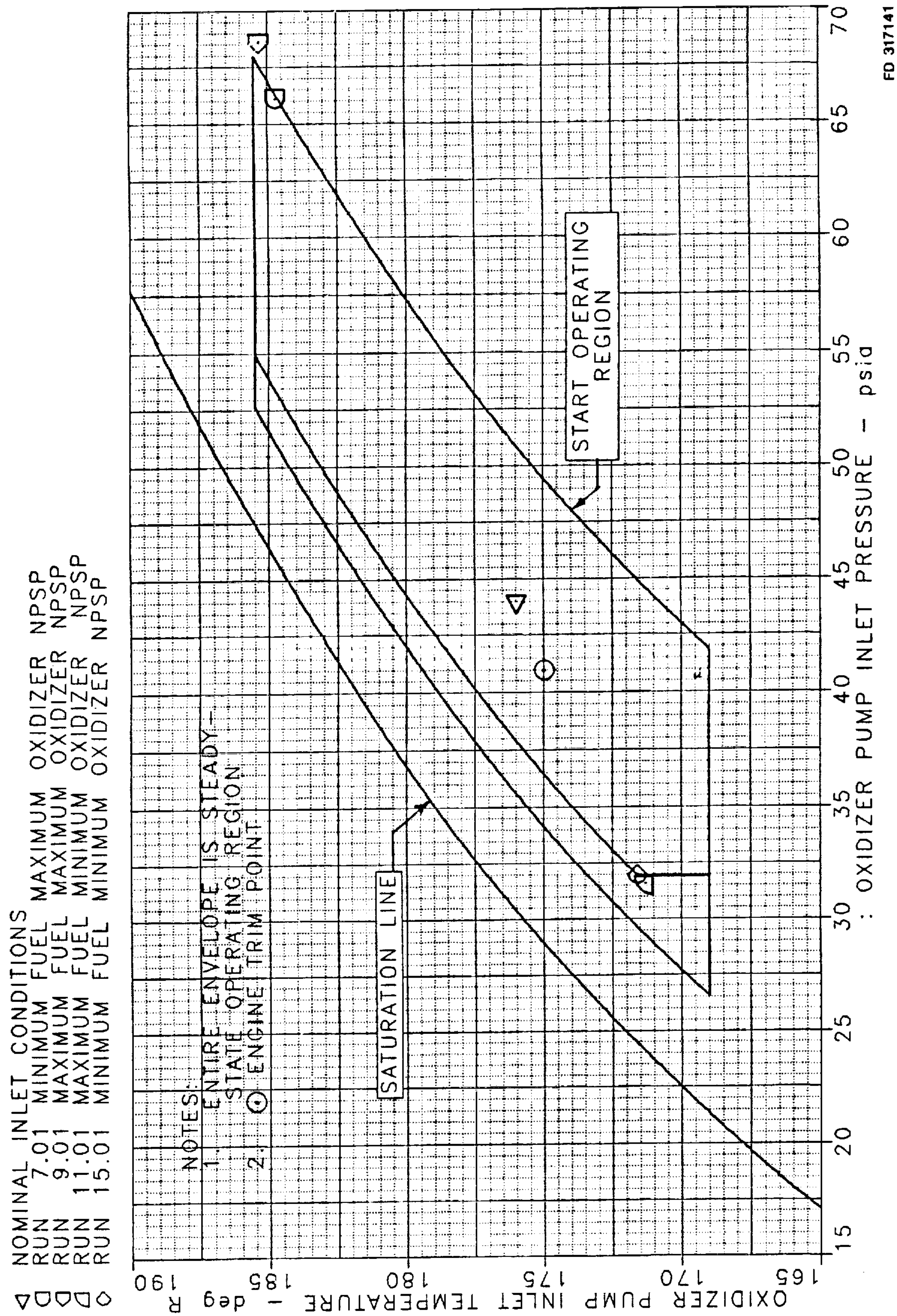

Figure V-32. Liquid Oxygen Pump Inlet Requirements

9046M

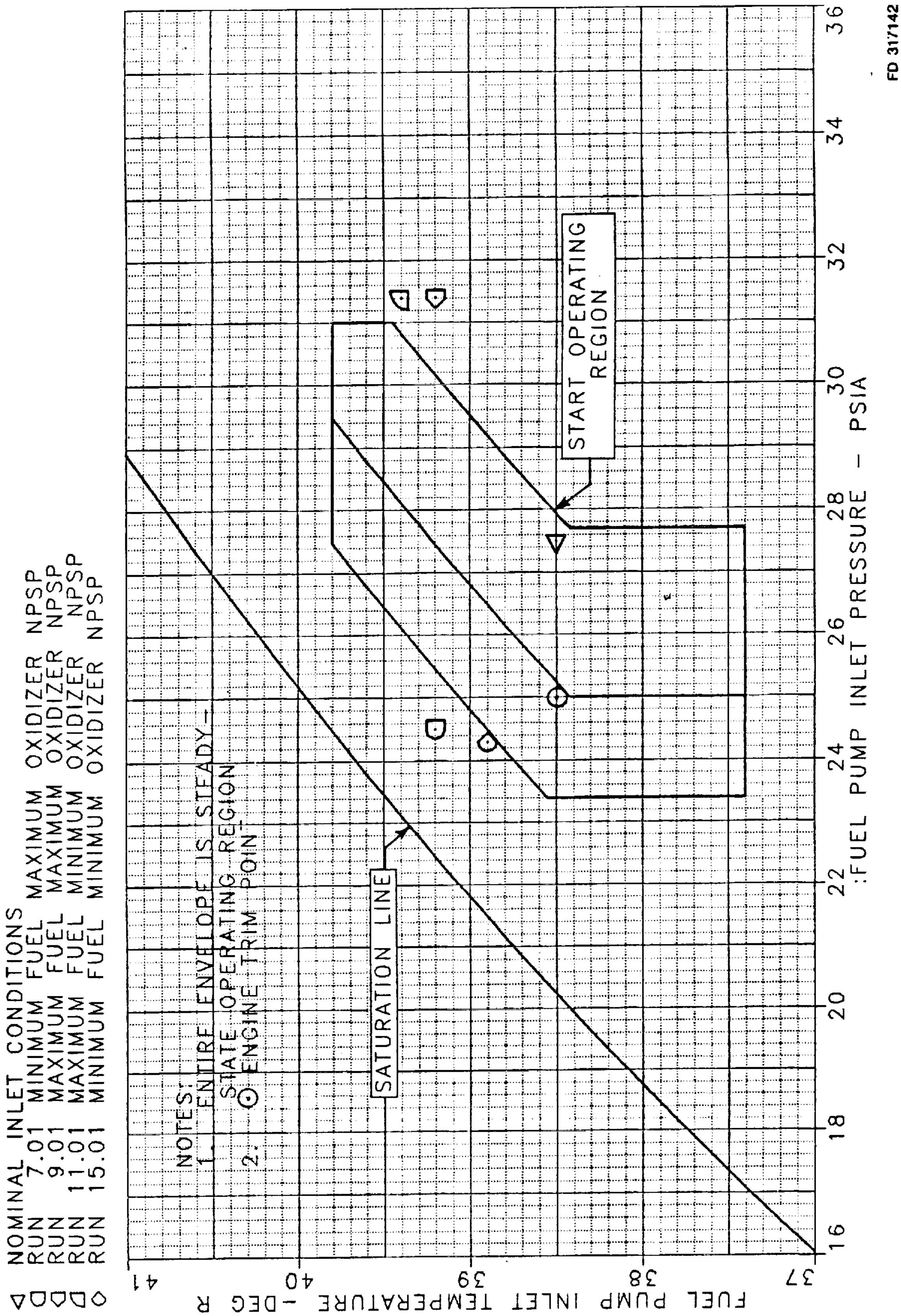

Figure V-33. Liquid Hydrogen Pump Inlet Requirements

C-2

9046M

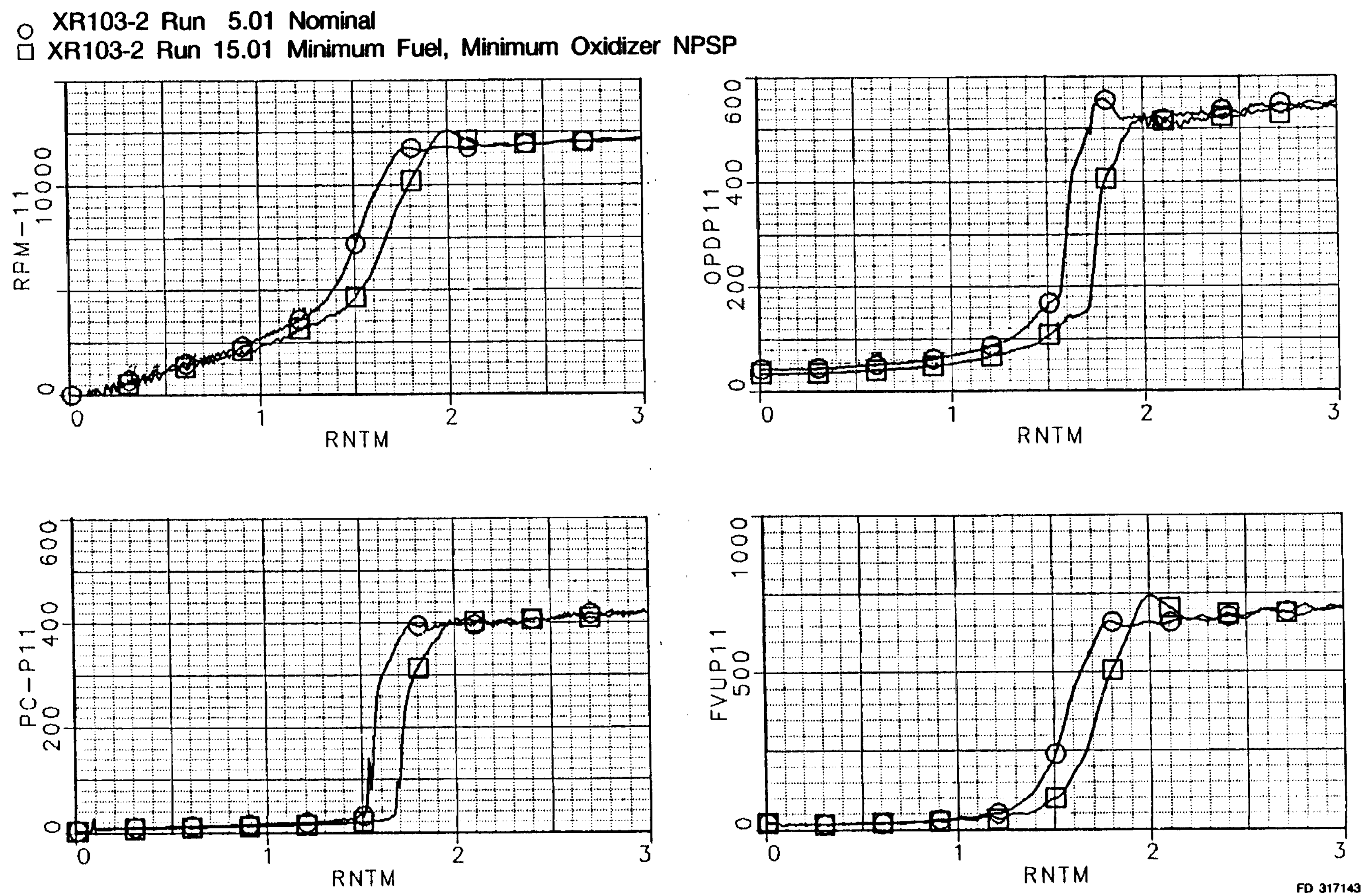

Figure V-34. Inlet Conditions Effect on Start Transient — RNTM

9046M

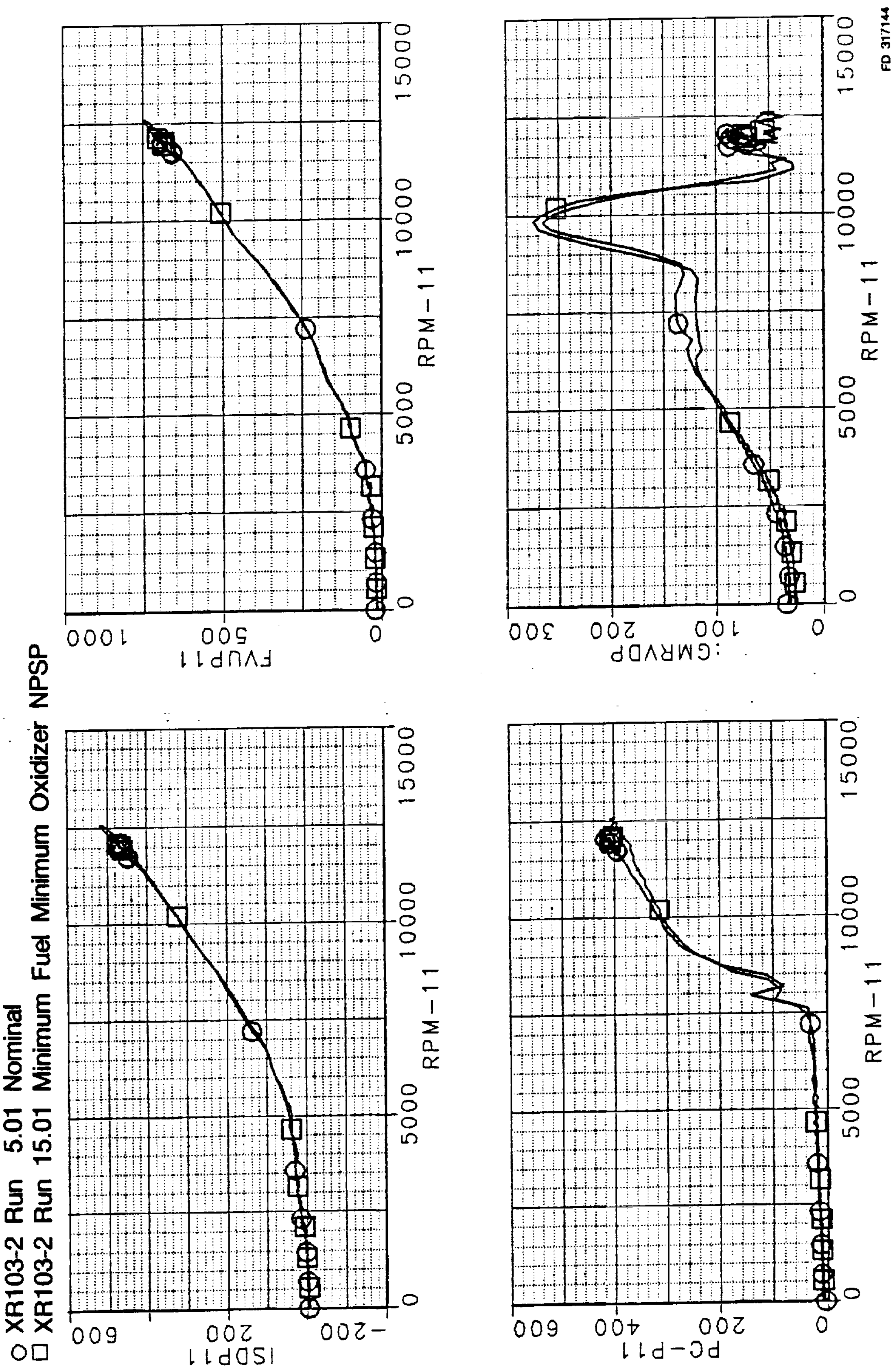

Figure V-35. Inlet Conditions Effect on Start Transient — RPM-11

9046M

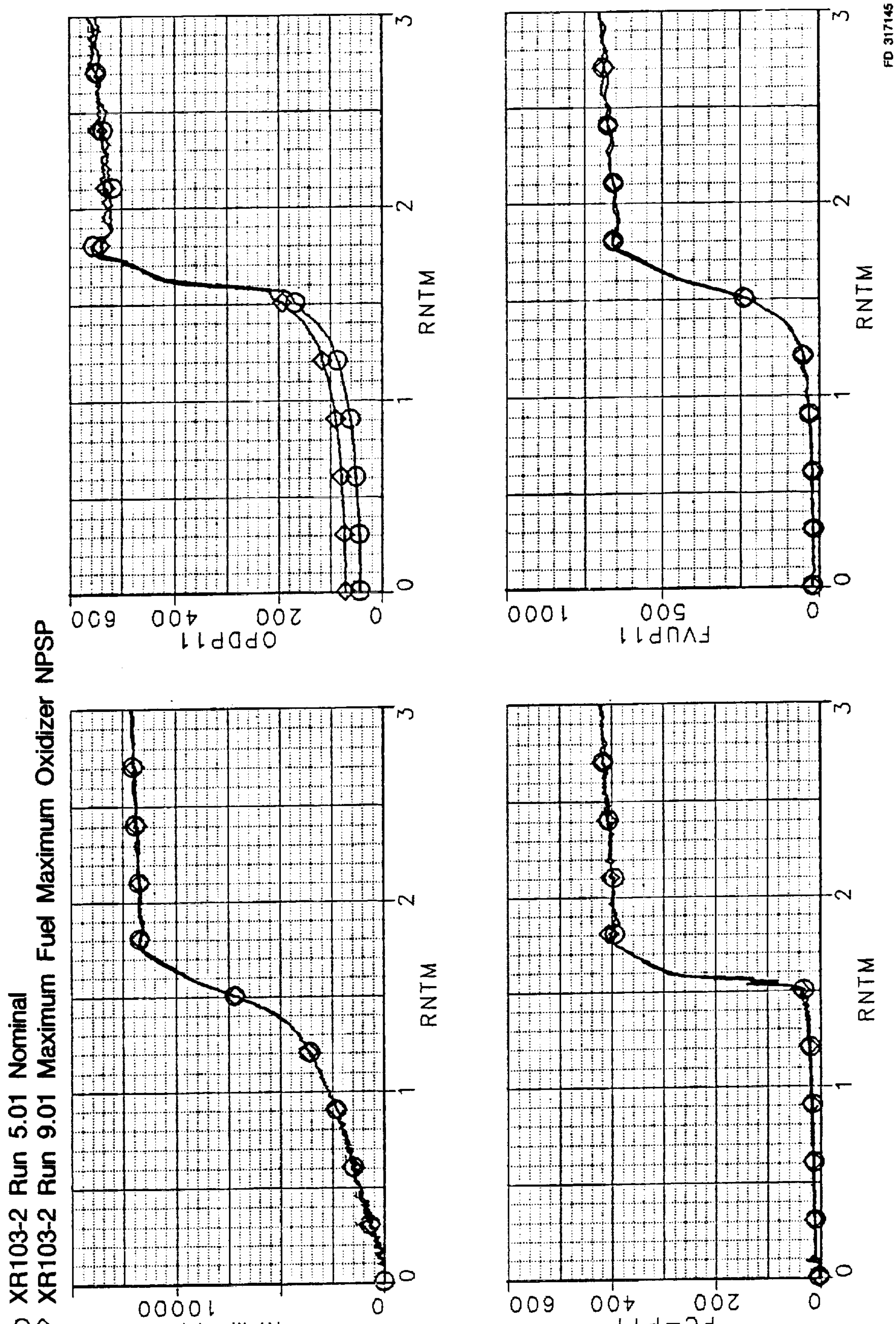

Figure V-36. Inlet Conditions Effect on Start Transient — RNTM

9046M

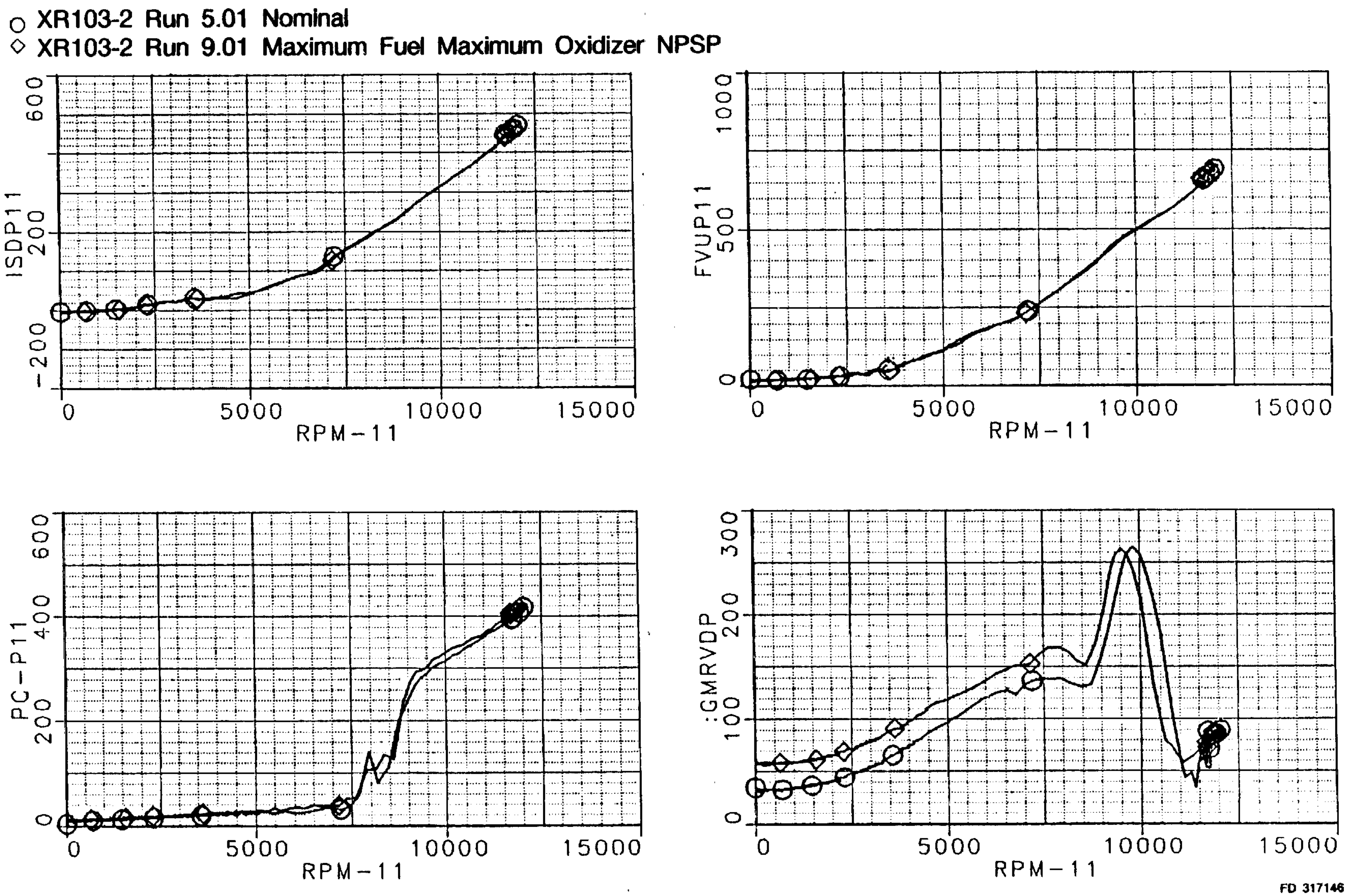

Figure V-37. Inlet Conditions Effect on Start Transient — RPM-11

9046M

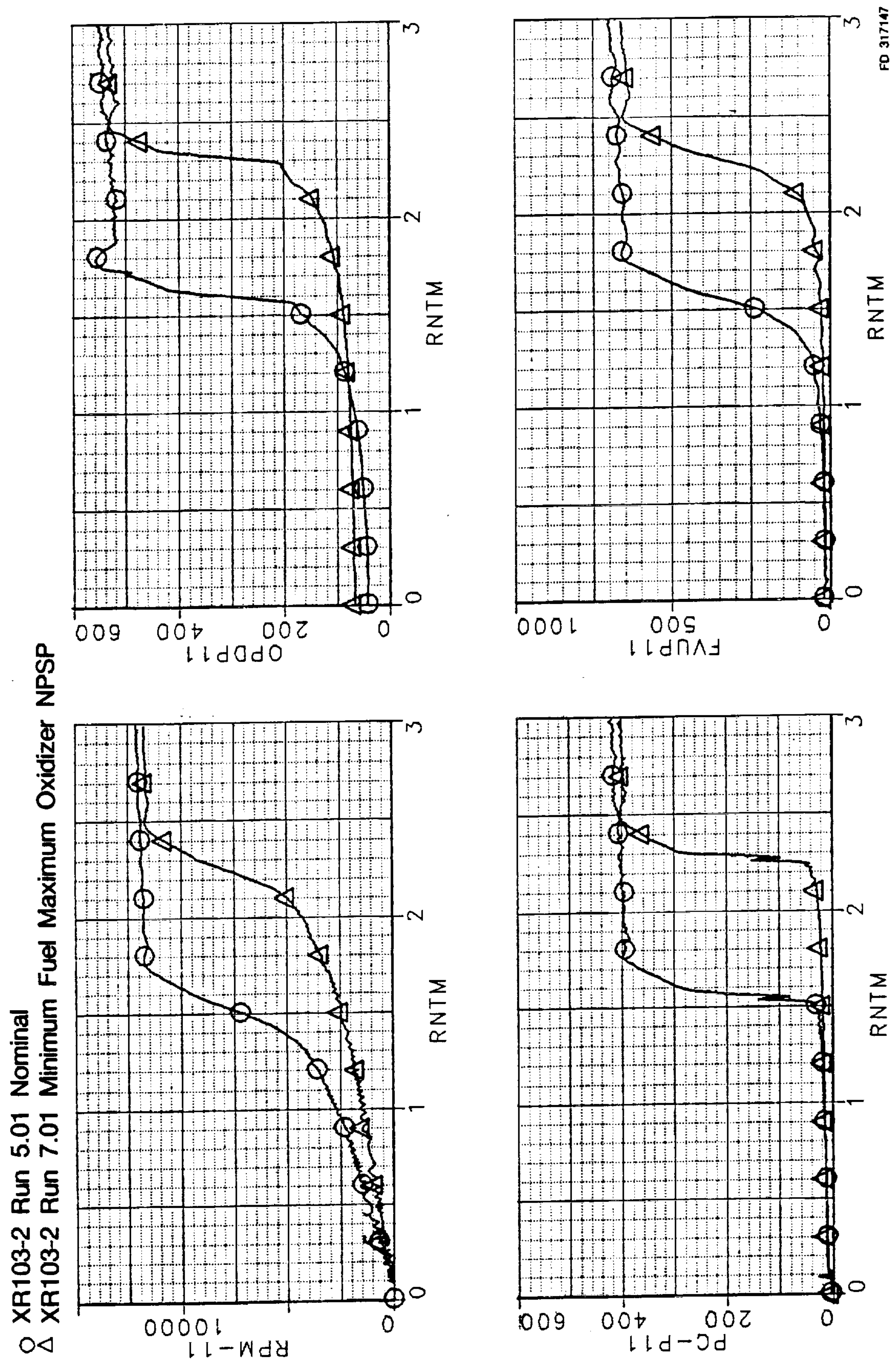

Figure V-38. Inlet Conditions Effect on Start Transient — RNTM

9046M

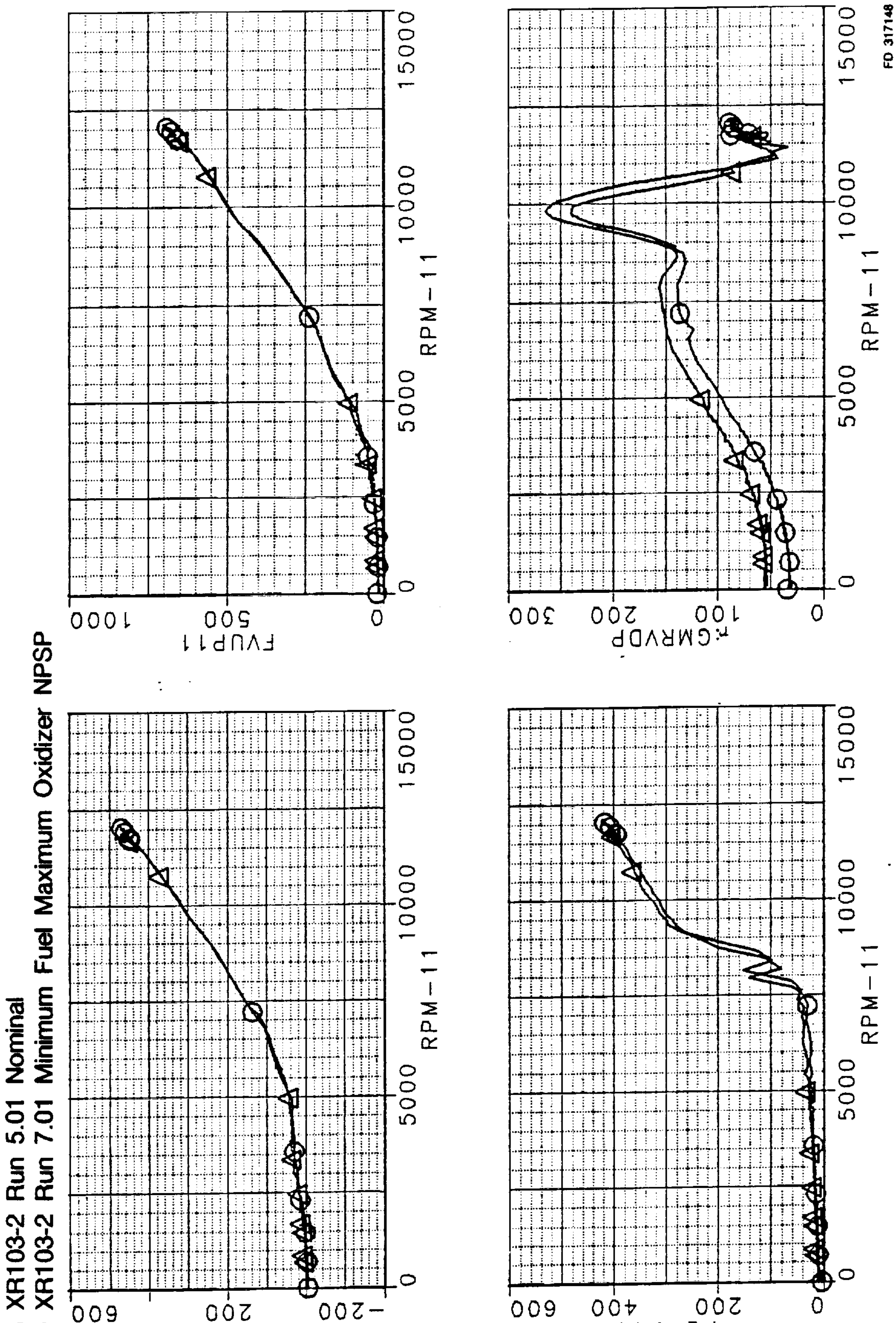

Figure V-39. Inlet Conditions Effect on Start Transient — RPM-11

9046M

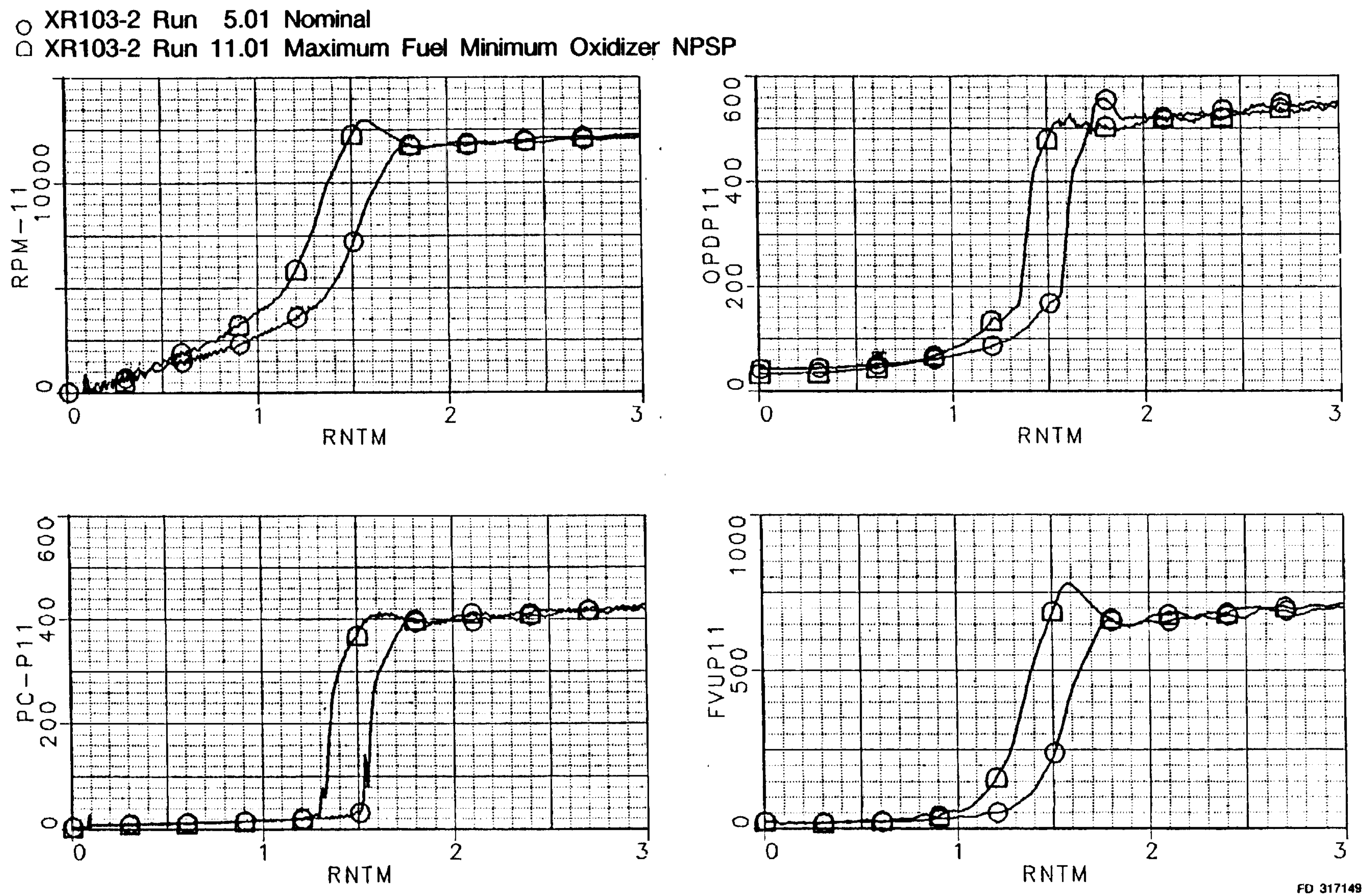

Figure V-40. Inlet Conditions Effect on Start Transient — RNTM

9046M

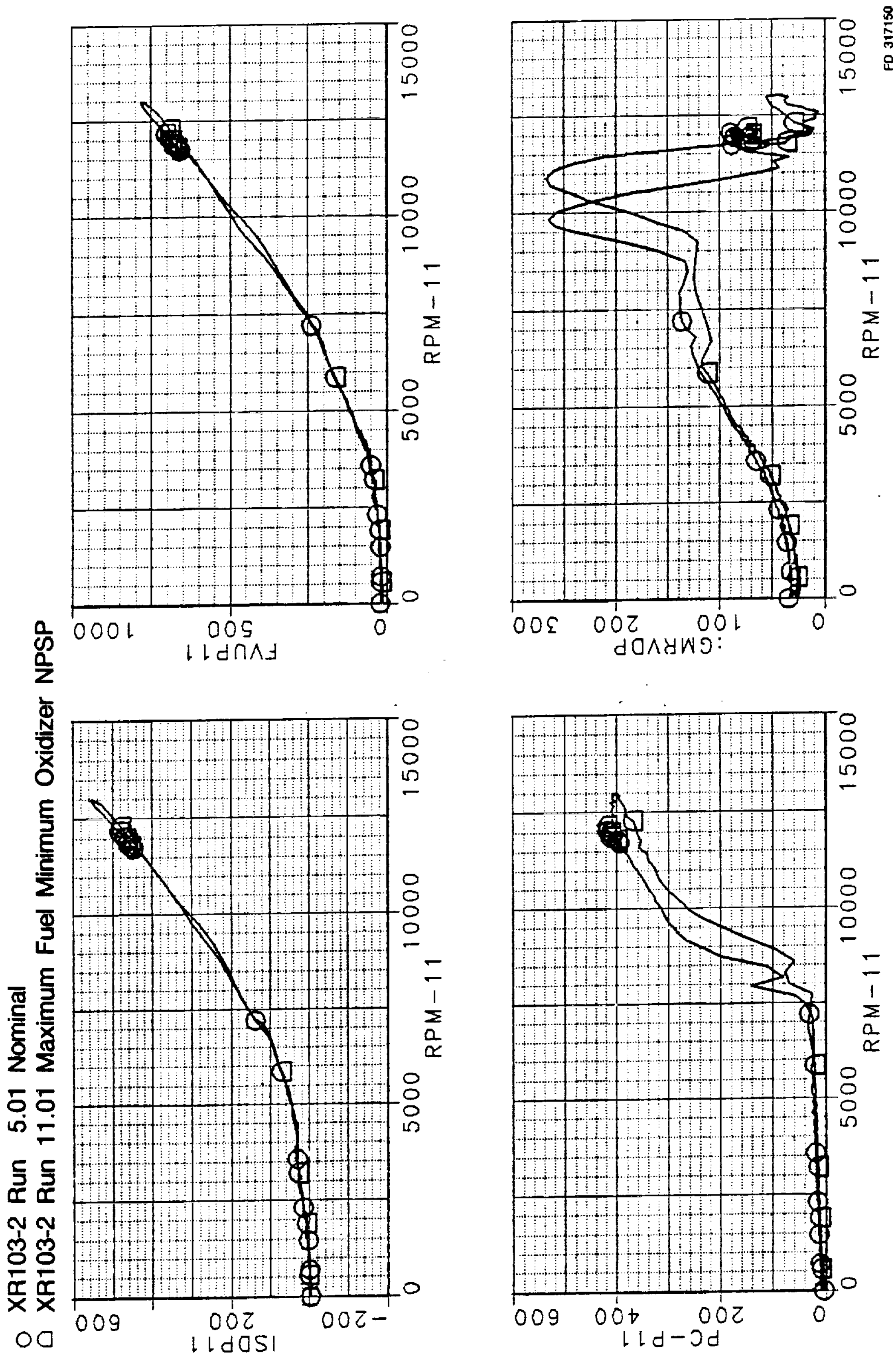

Figure V-41. Inlet Conditions Effect on Start Transient — RPM-11

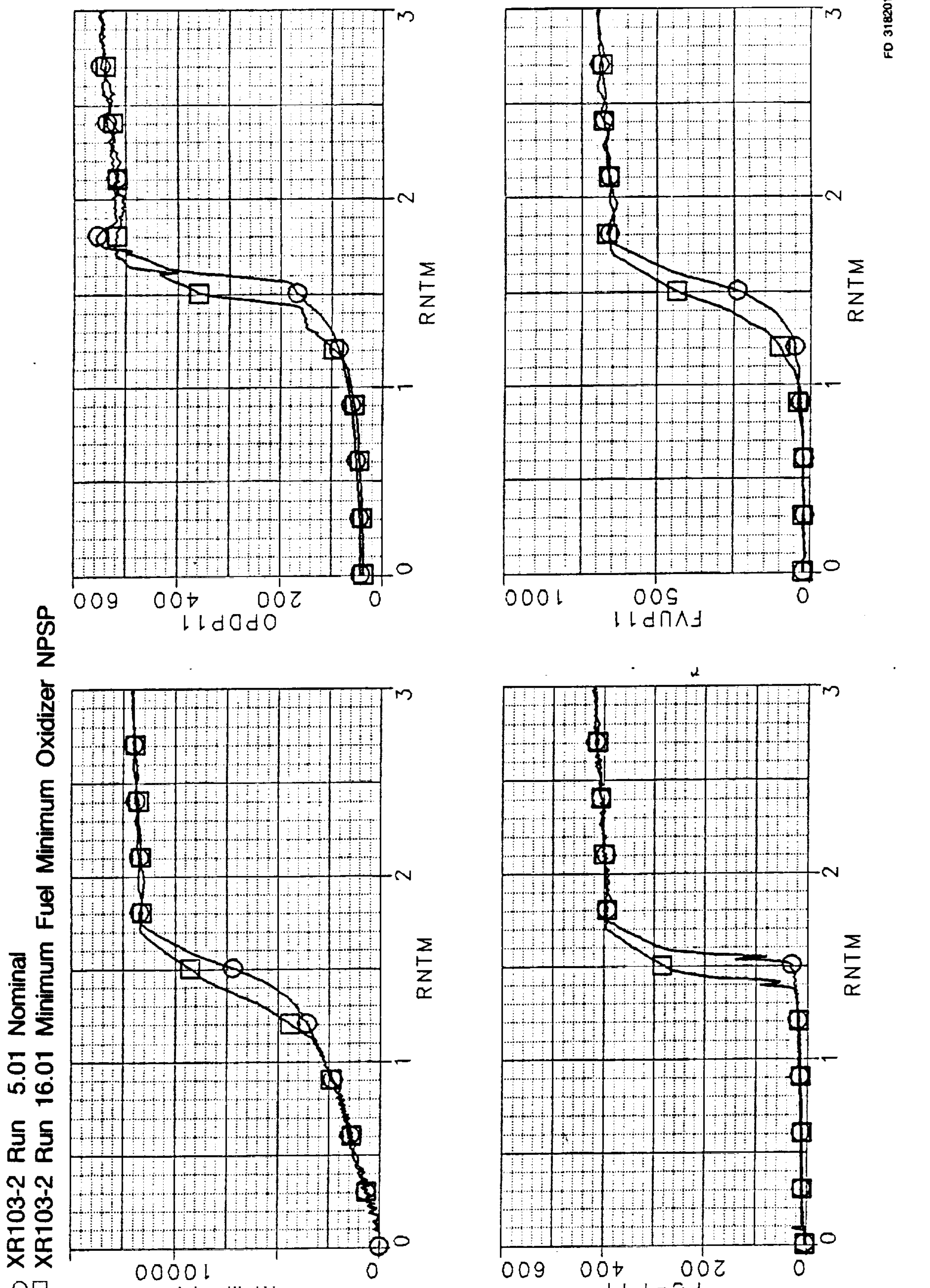

Figure V-42. Inlet Conditions Effect on Start Transient: Relight — RNTM

9046M

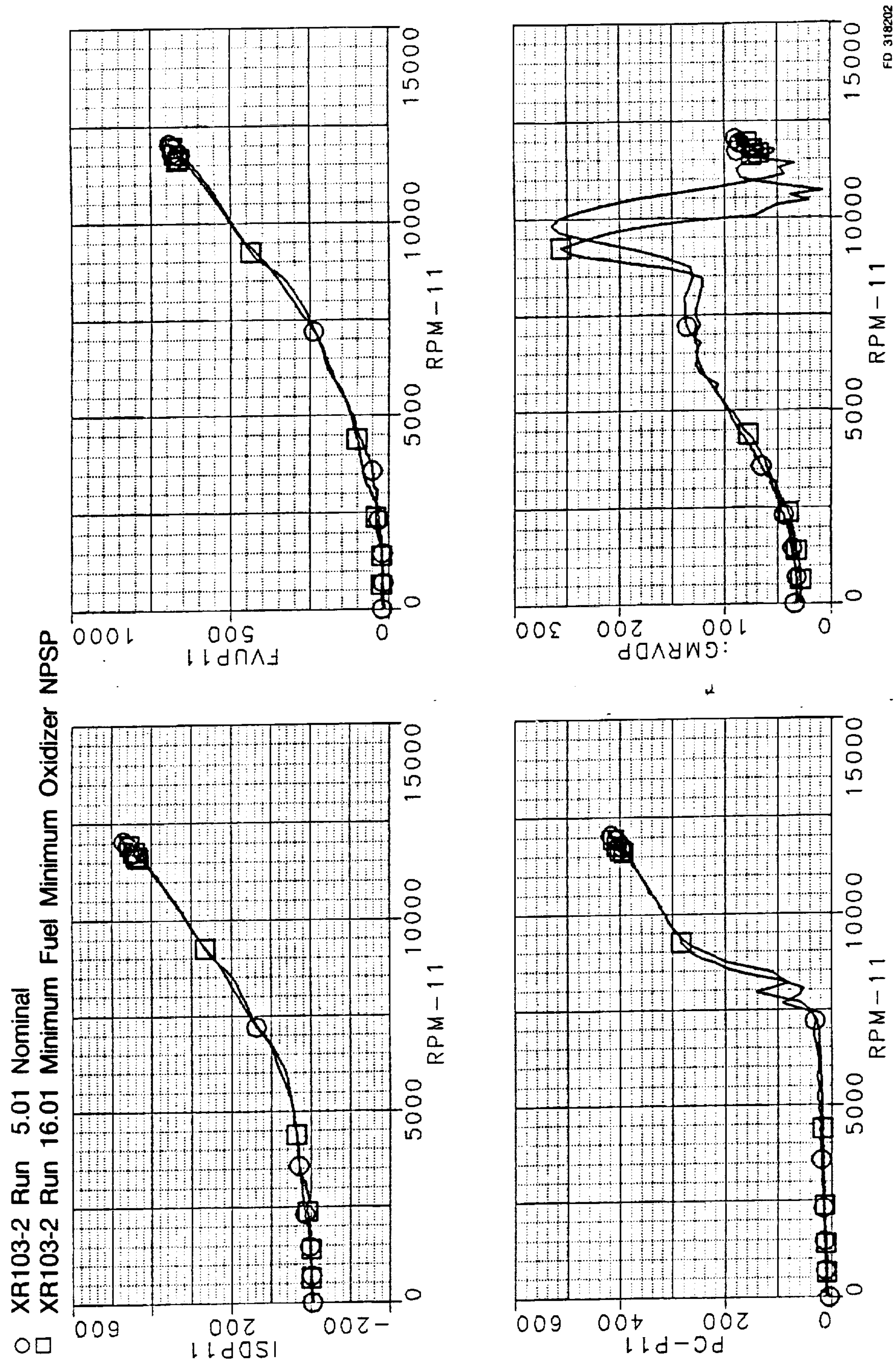

Figure V-43. Inlet Conditions Effect on Start Transient: Relight — RPM-11

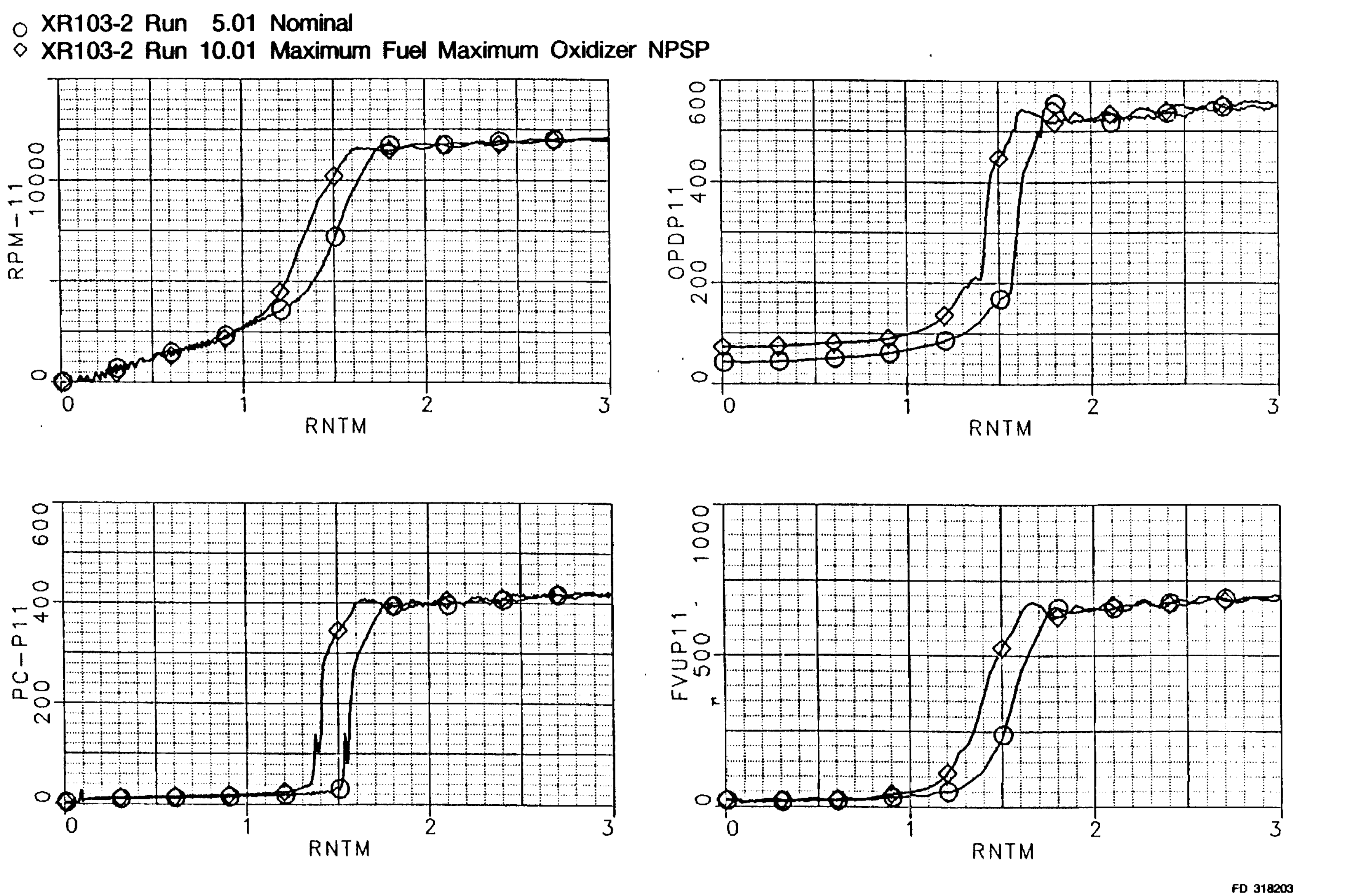

Figure V-44. Inlet Conditions Effect on Start Transient: Relight — RNTM

9046M

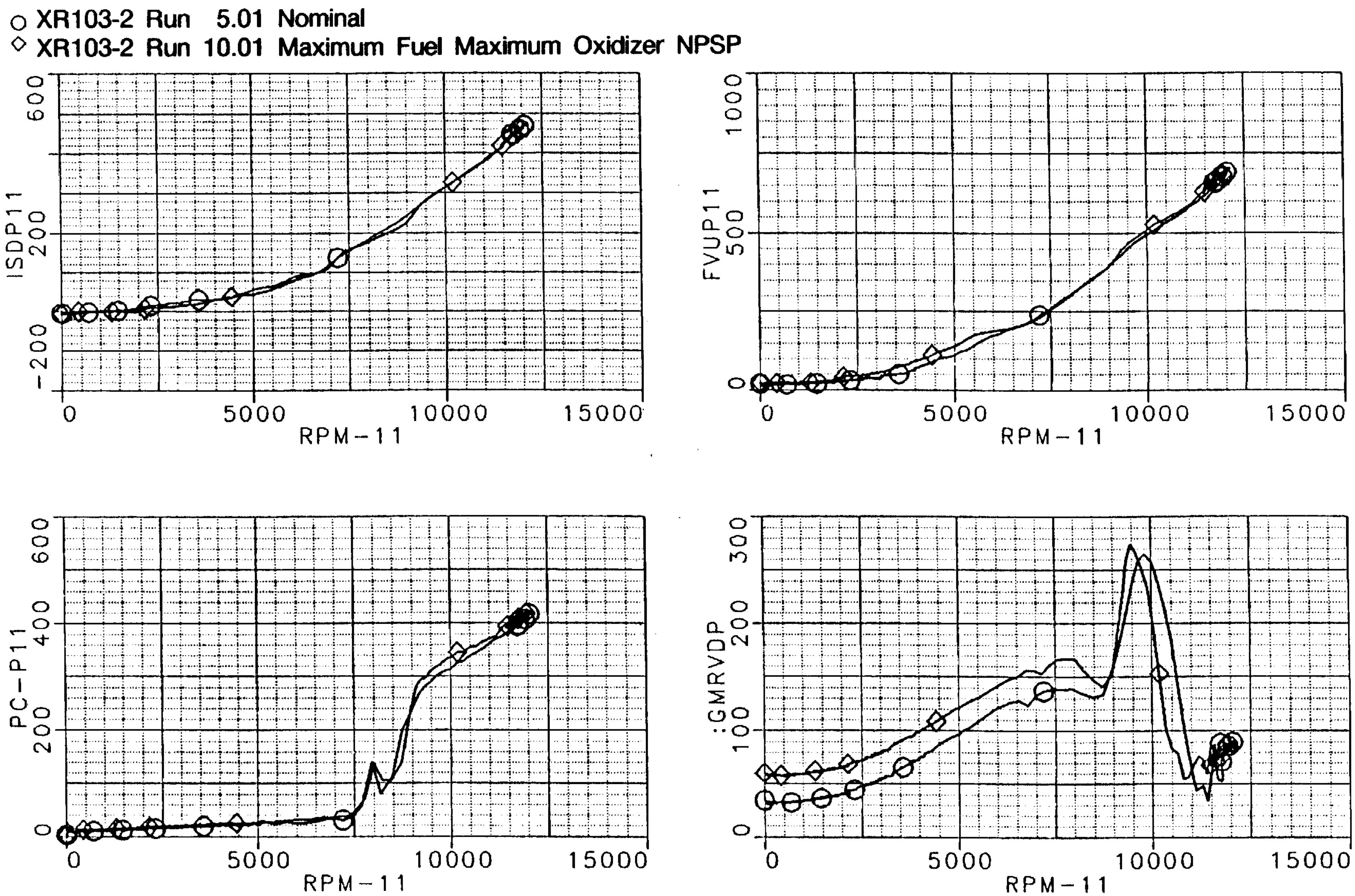

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Figure V-45. Inlet Conditions Effect on Start Transient: Relight — RPM-11

9046M

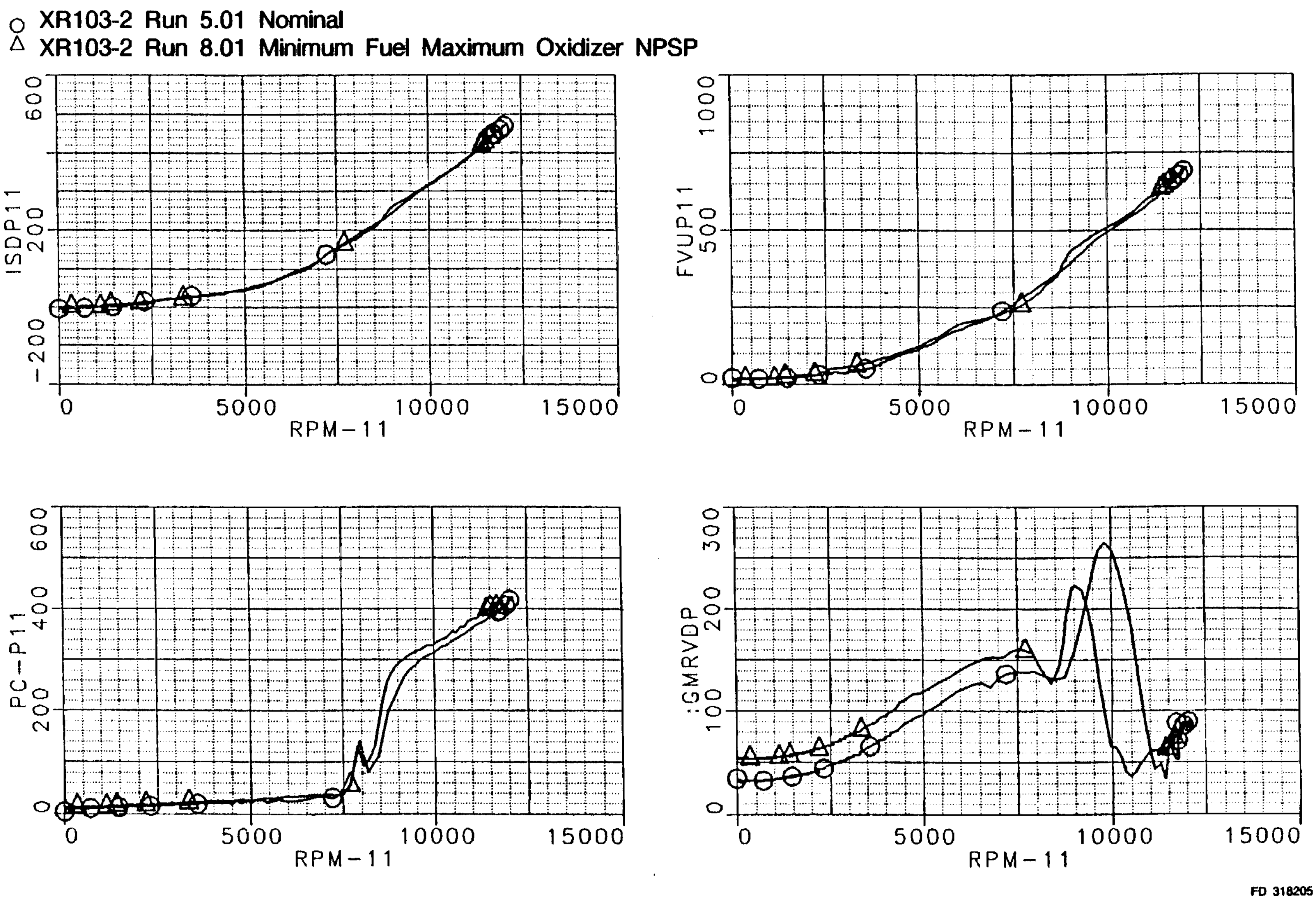

Figure V-46. Inlet Conditions Effect on Start Transient: Relight — RPM-11

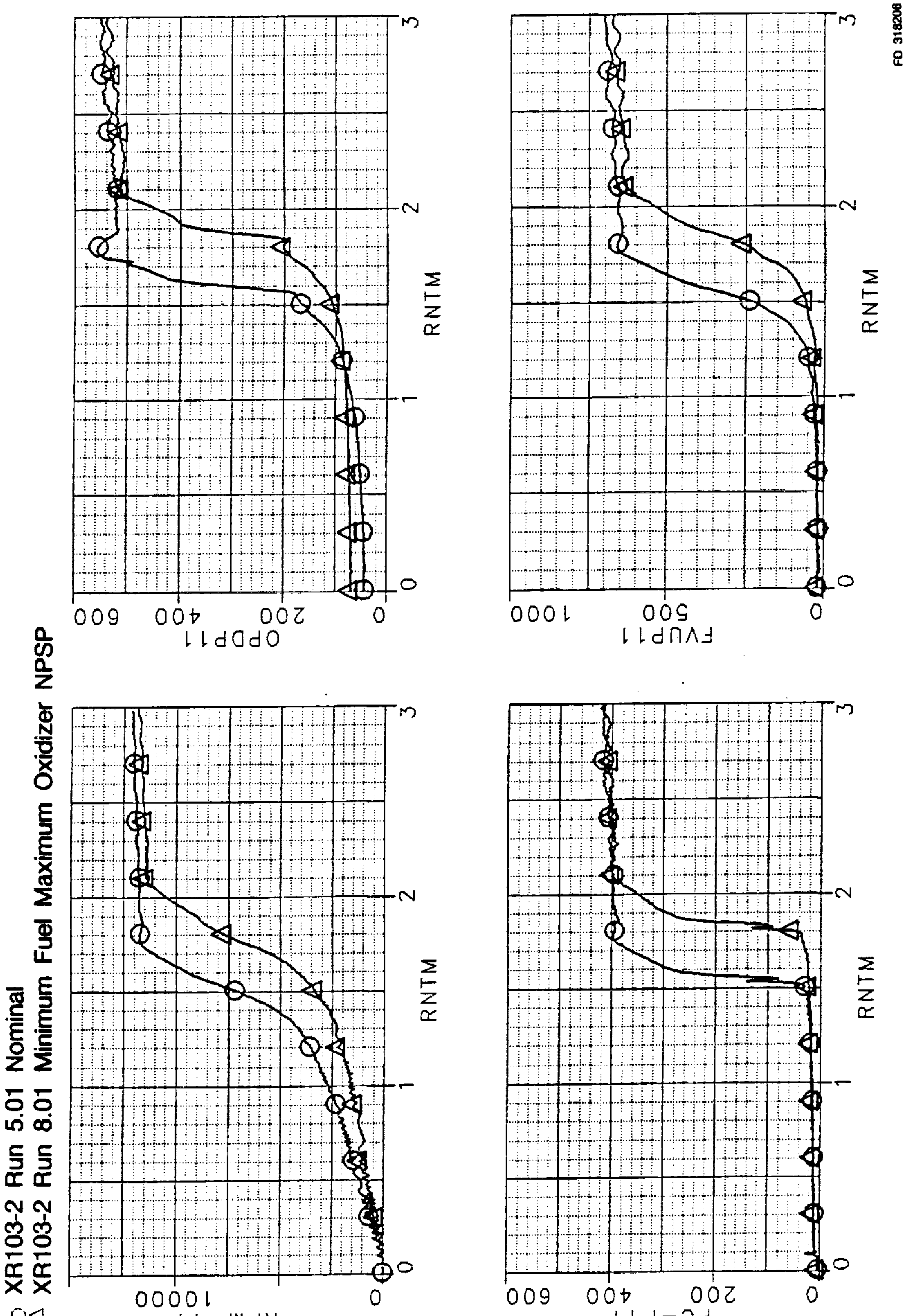

Figure V-47. Inlet Conditions Effect on Start Transient: Relight — RNTM

9046M

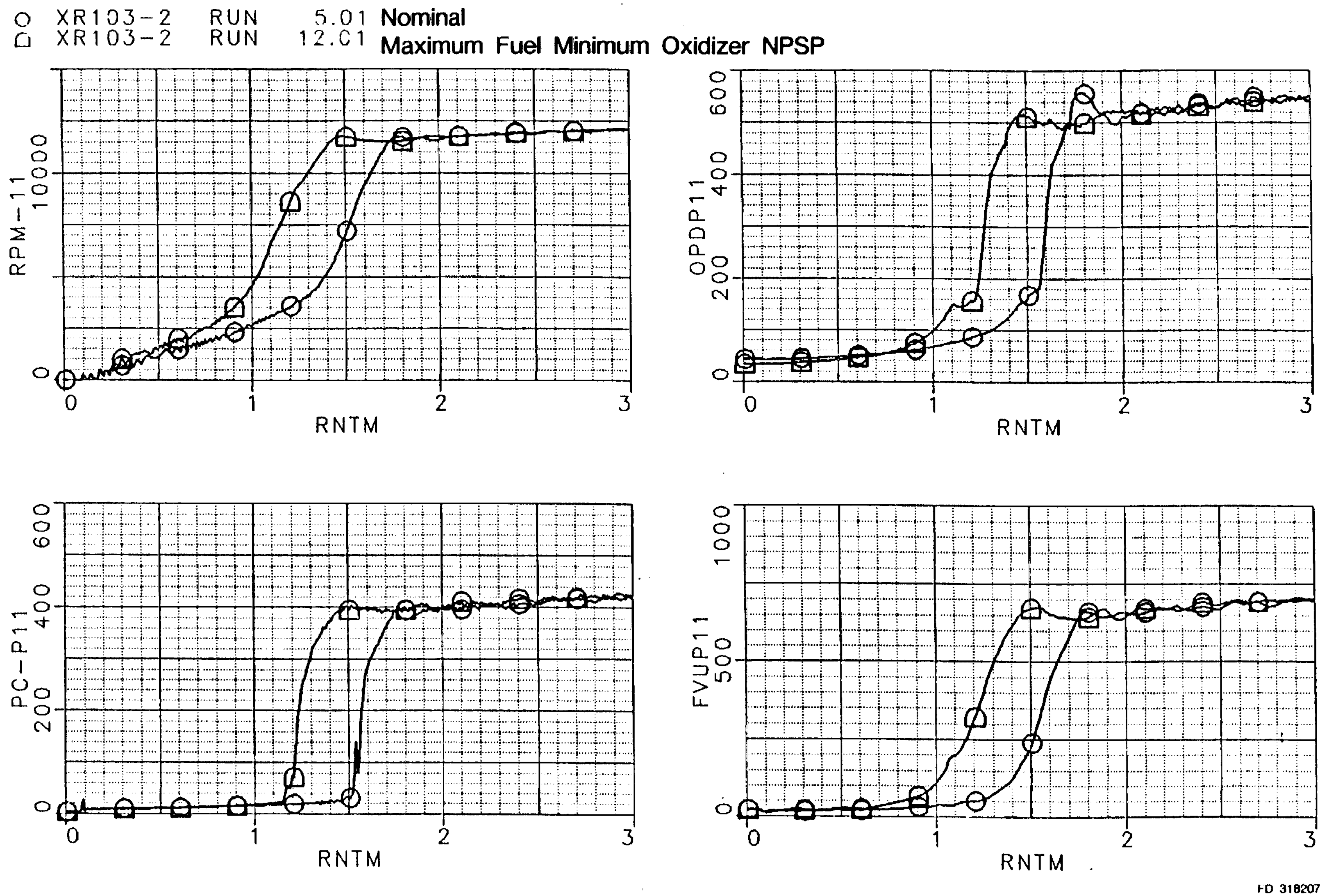

Figure V-48. Inlet Conditions Effect on Start Transient: Relight — RNTM

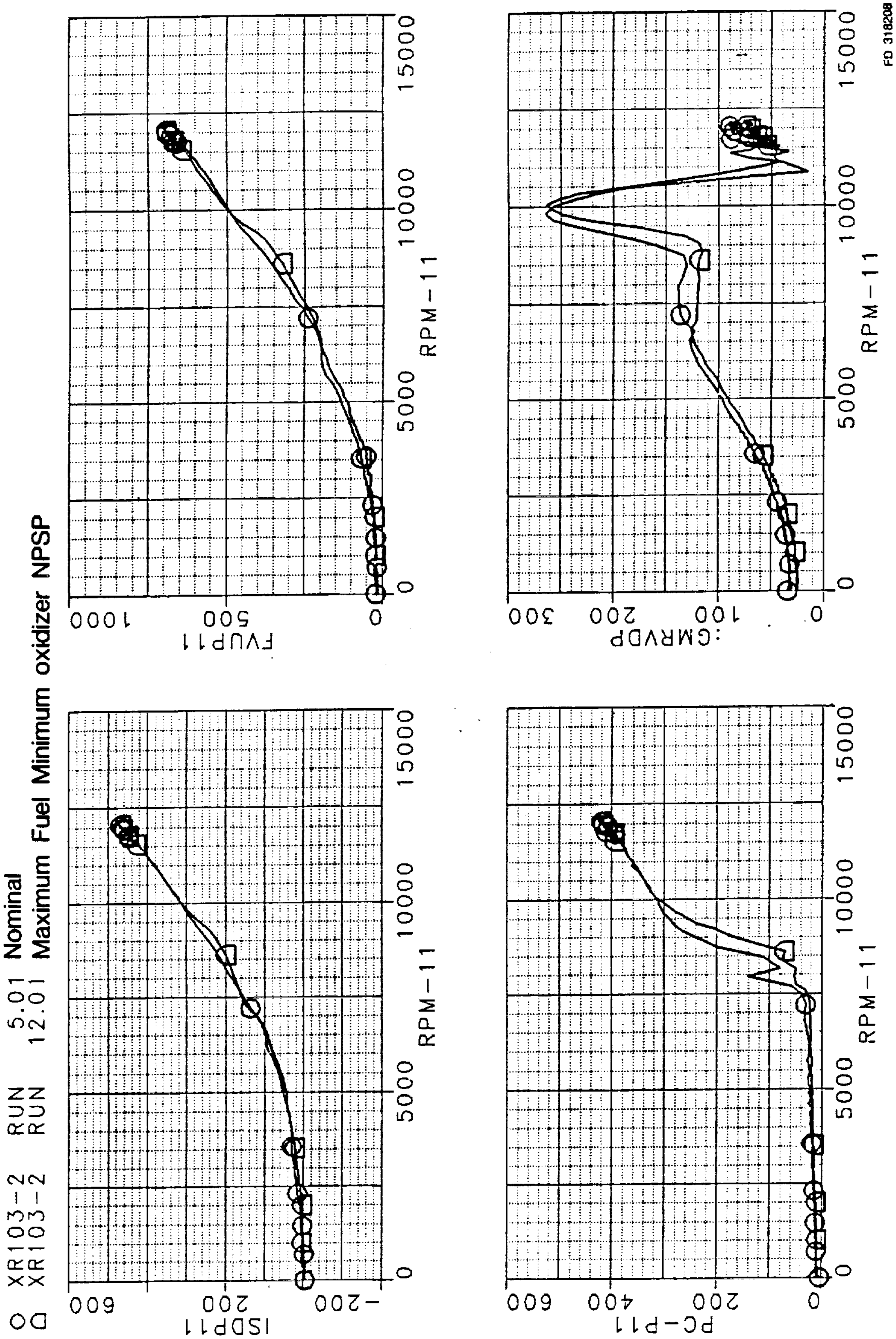

Figure V-49. Inlet Conditions Effect on Start Transient: Relight — RPM-11

9046M

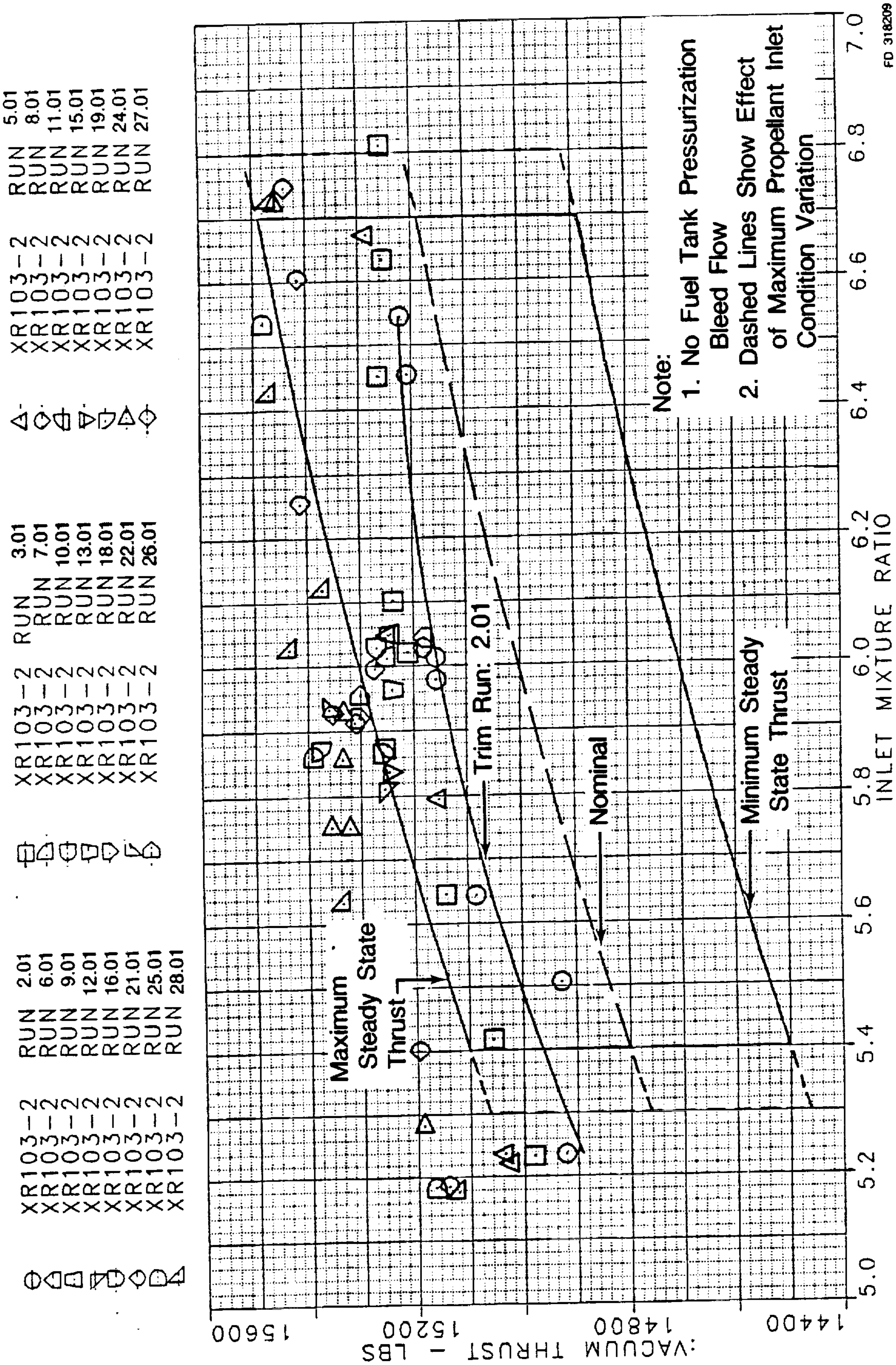

Figure V-50. Inlet Mixture Ratio Effect on Vacuum Thrust

9046M

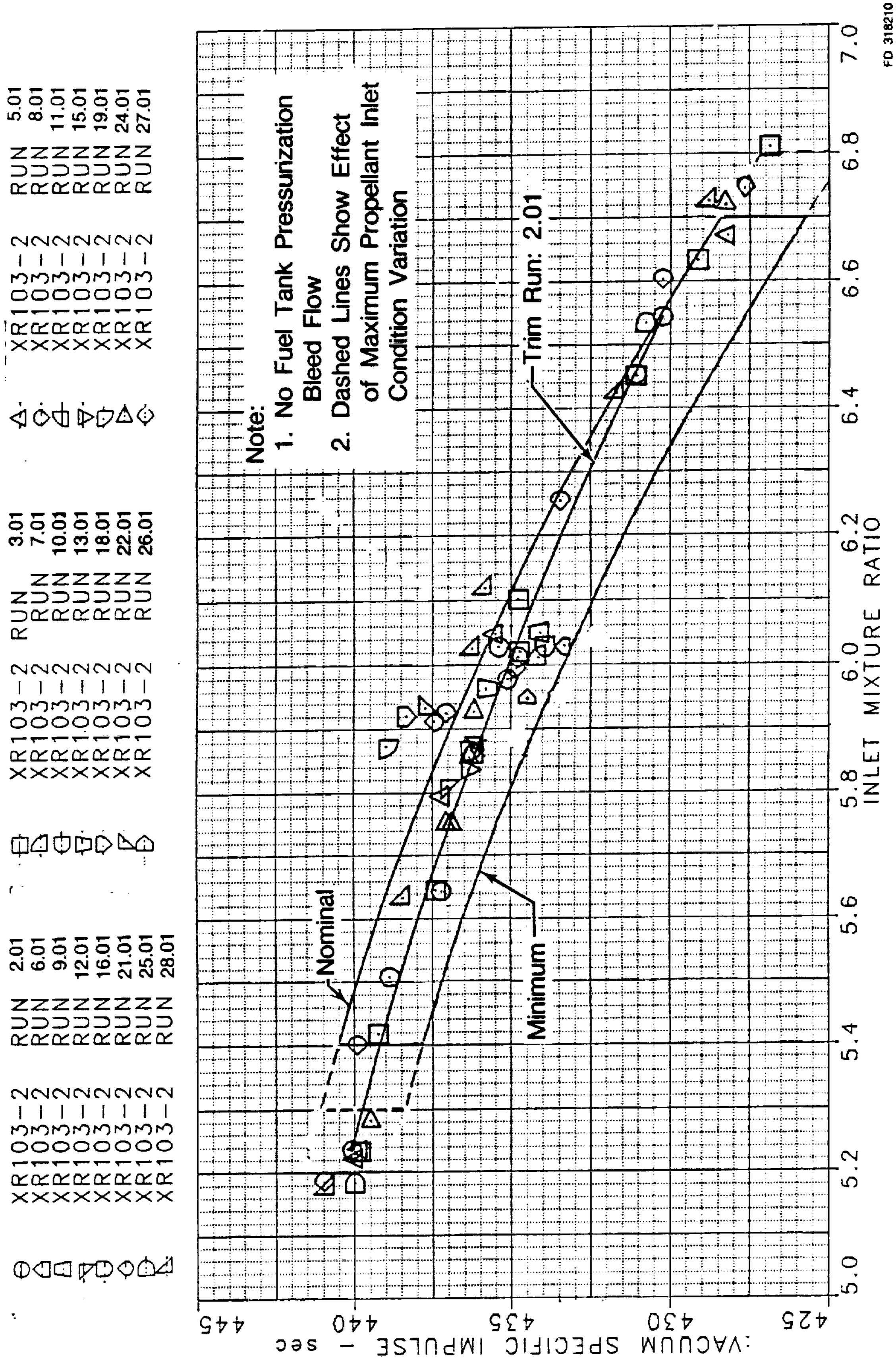

Figure V-51. Inlet Mixture Ratio Effect on Specific Impulse

9046M

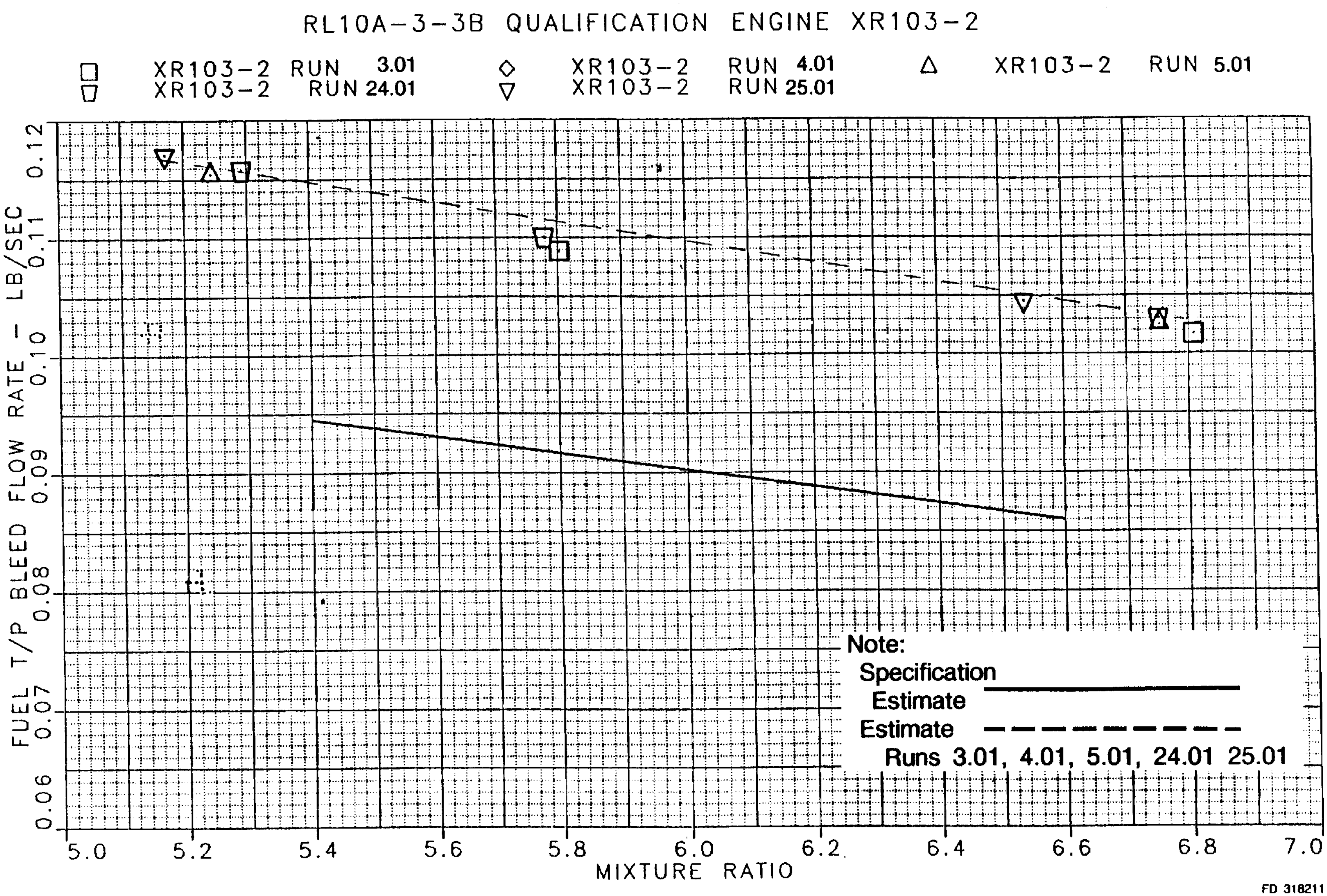

Figure V-52. *Effect of Mixture Ratio on Fuel Tank Pressurization Bleed Flow Rate*

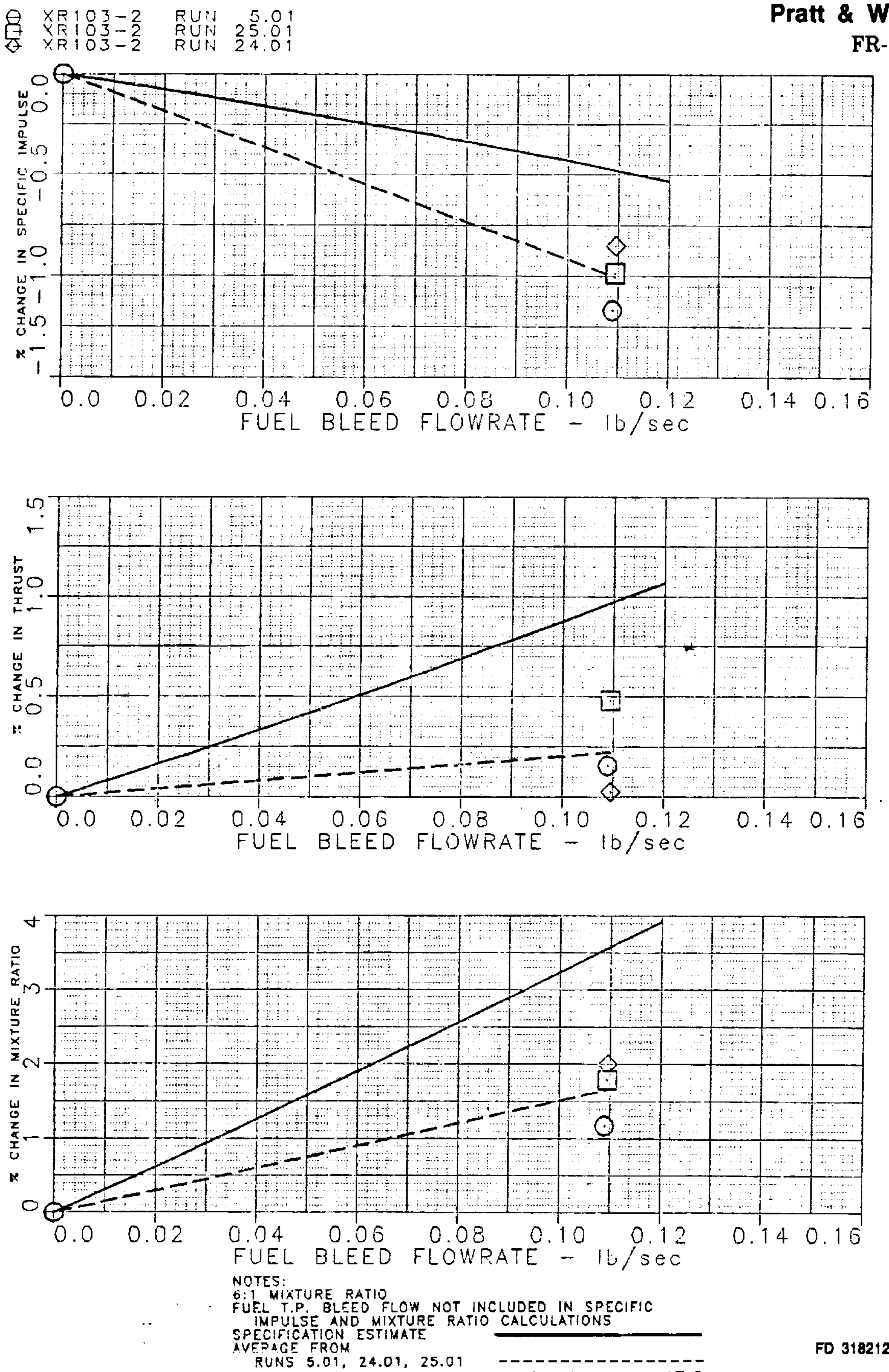

Figure V-53. Estimated Effect of Fuel Tank Pressurization Bleed Flow on Engine Performance

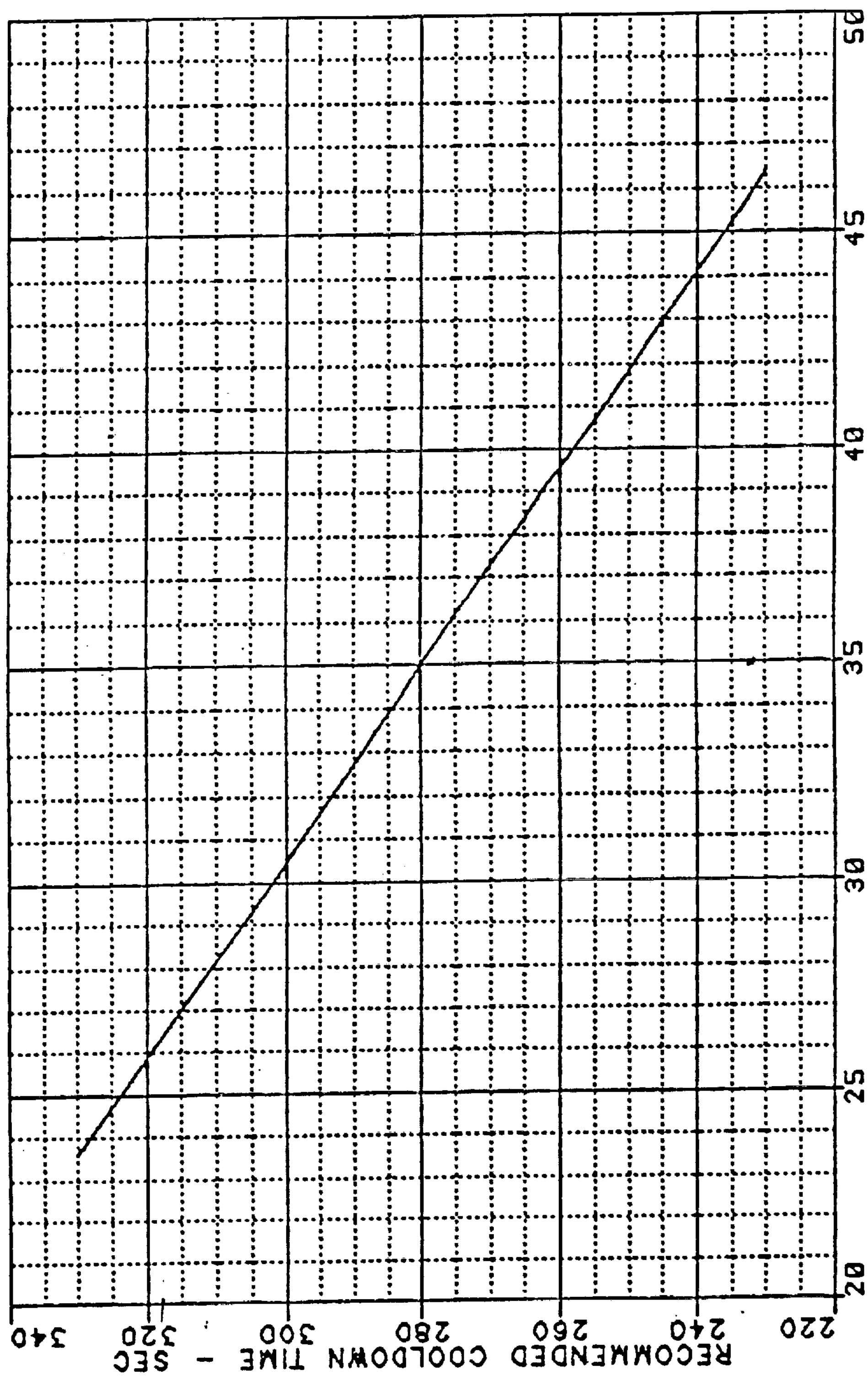

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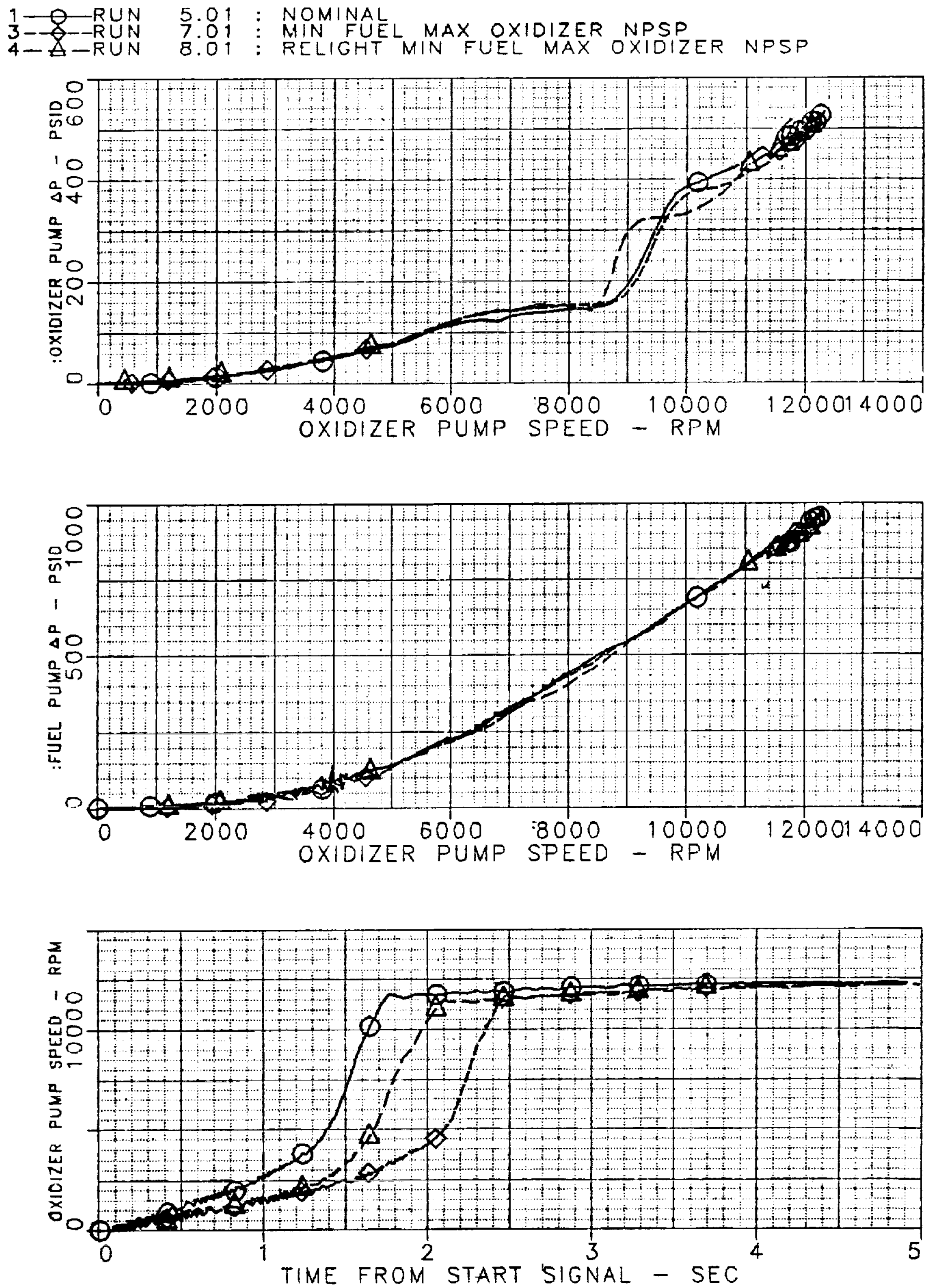
Figure V-54. Oxidizer Cooldown Limits

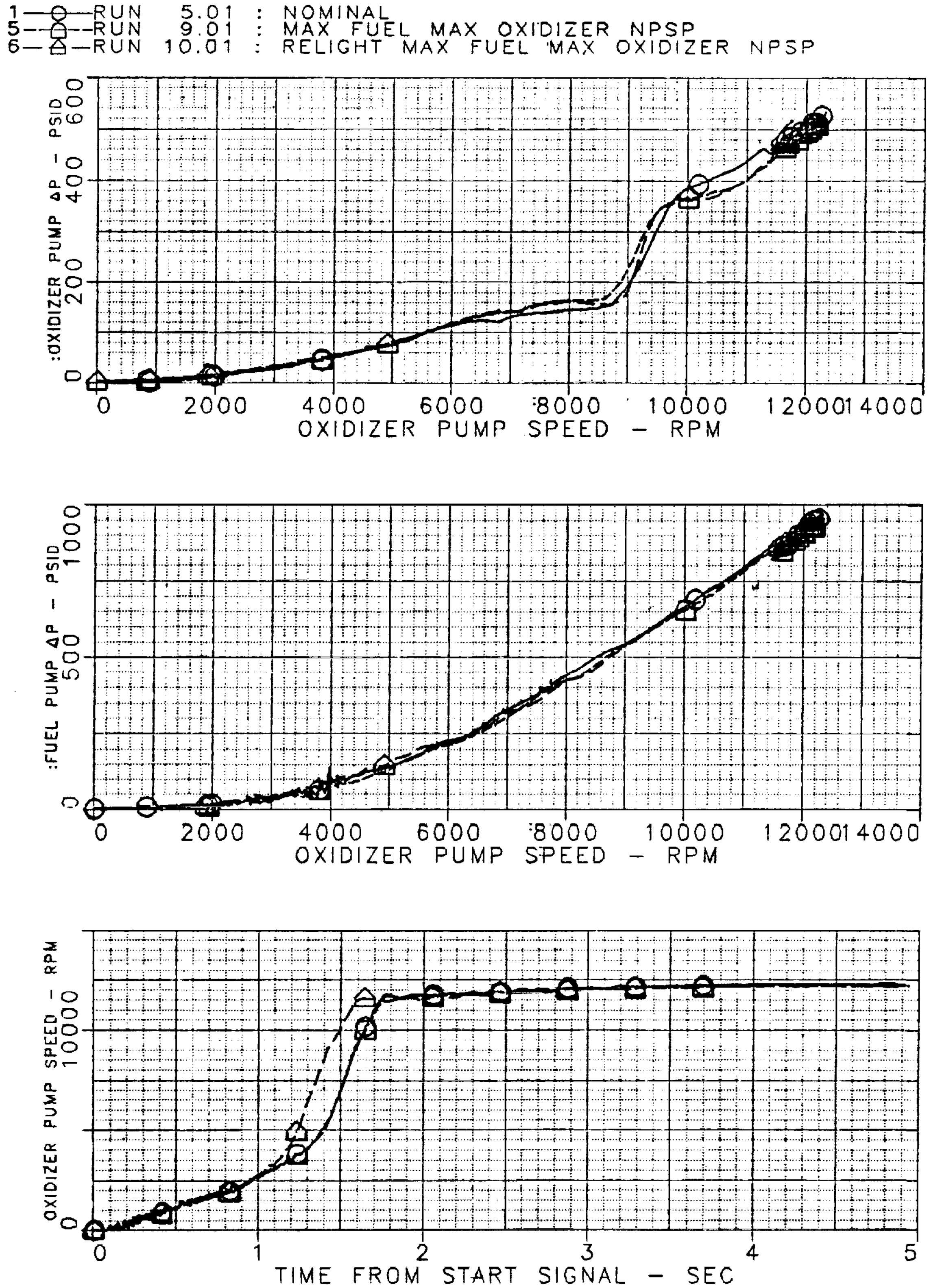
9046M



FD 318214

Figure V-55. Turbopump Cavitation Cooldown Limit and Relight Tests

9046M



FD 318215

Figure V-56. Turbopump Cavitation Cooldown Limit and Relight Tests

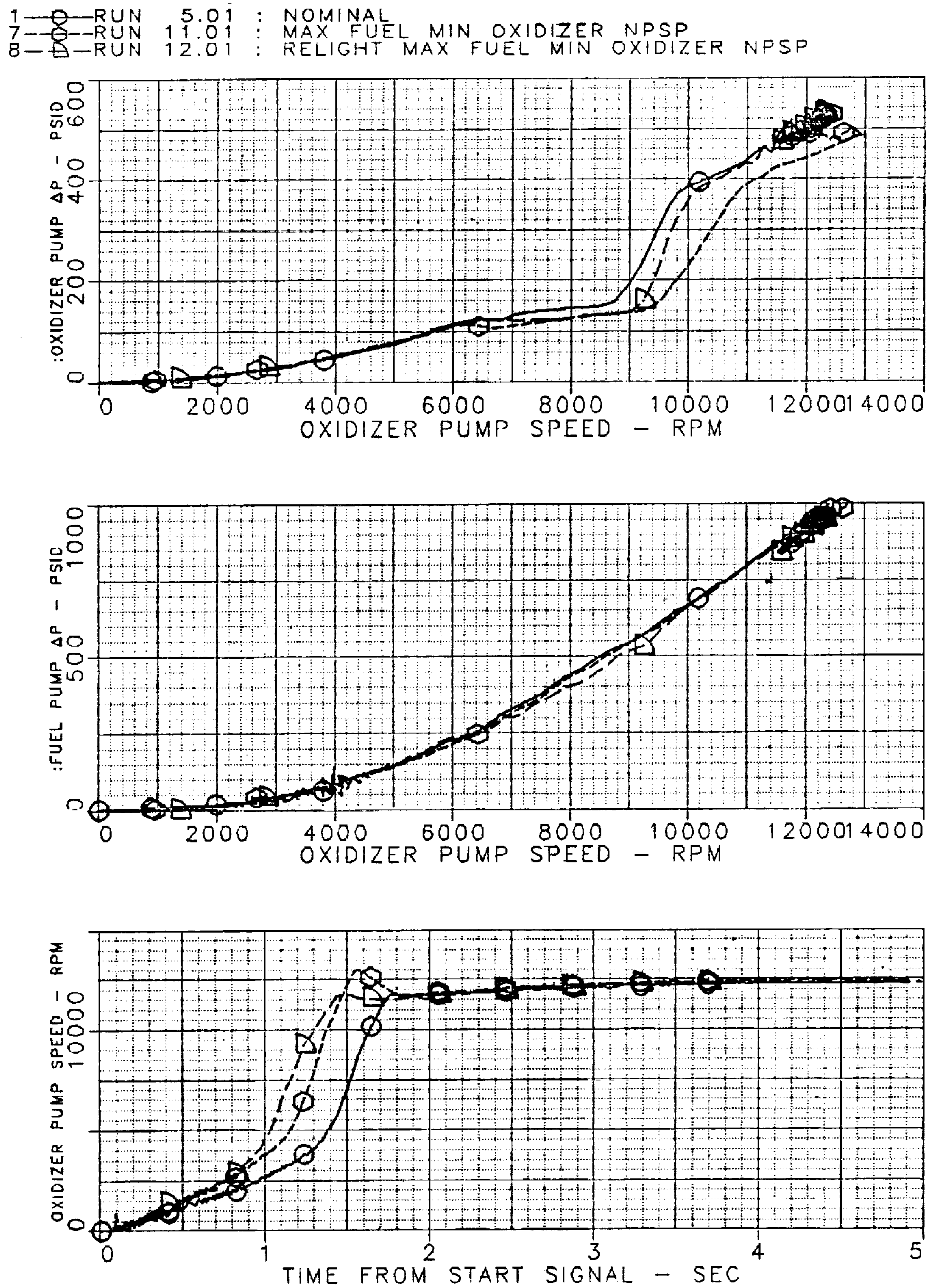


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Figure V-57. Turbopump Cavitation Cooldown Limit and Relight Tests

9046M

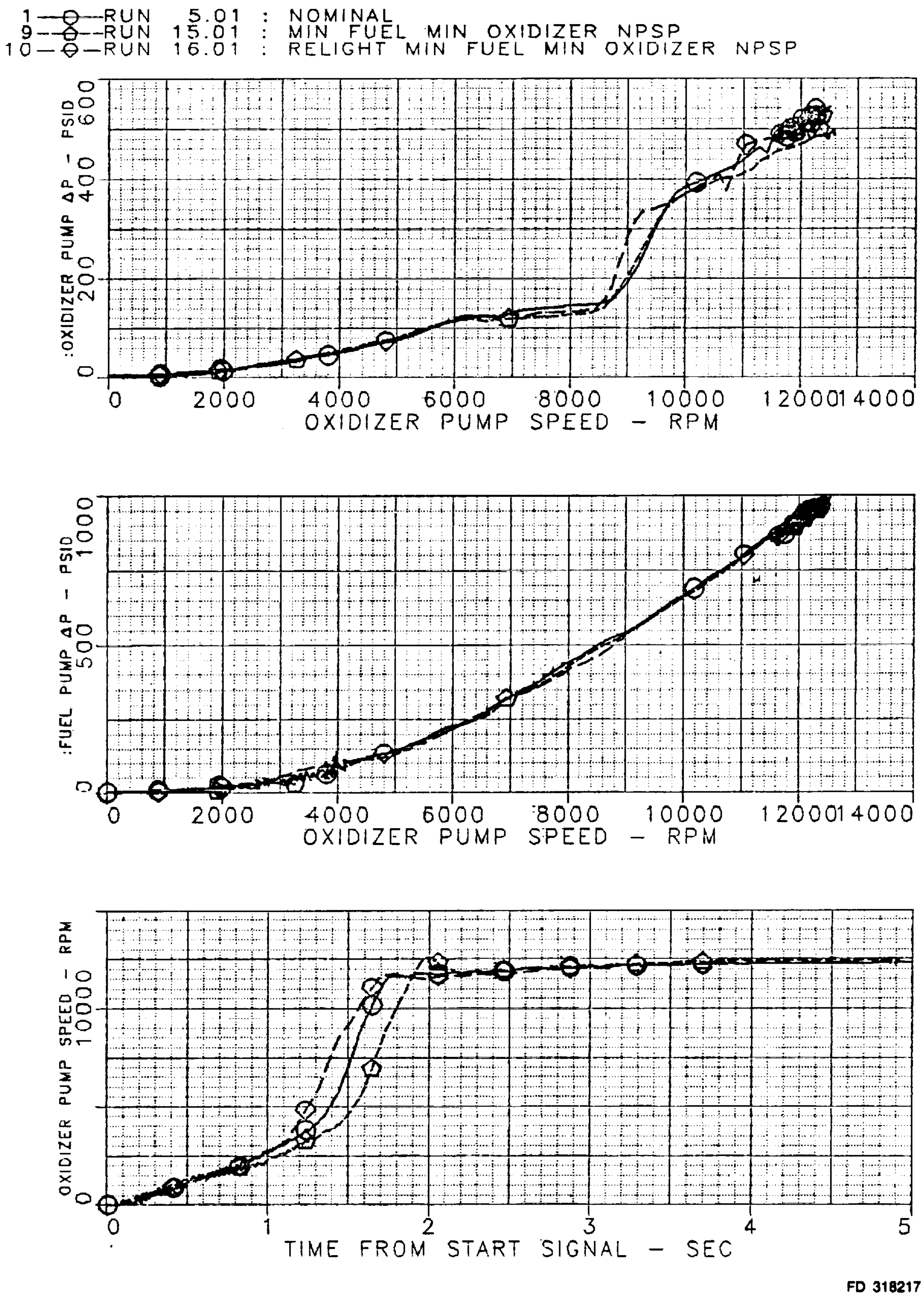

Figure V-58. Turbopump Cavitation Cooldown Limit and Relight Tests

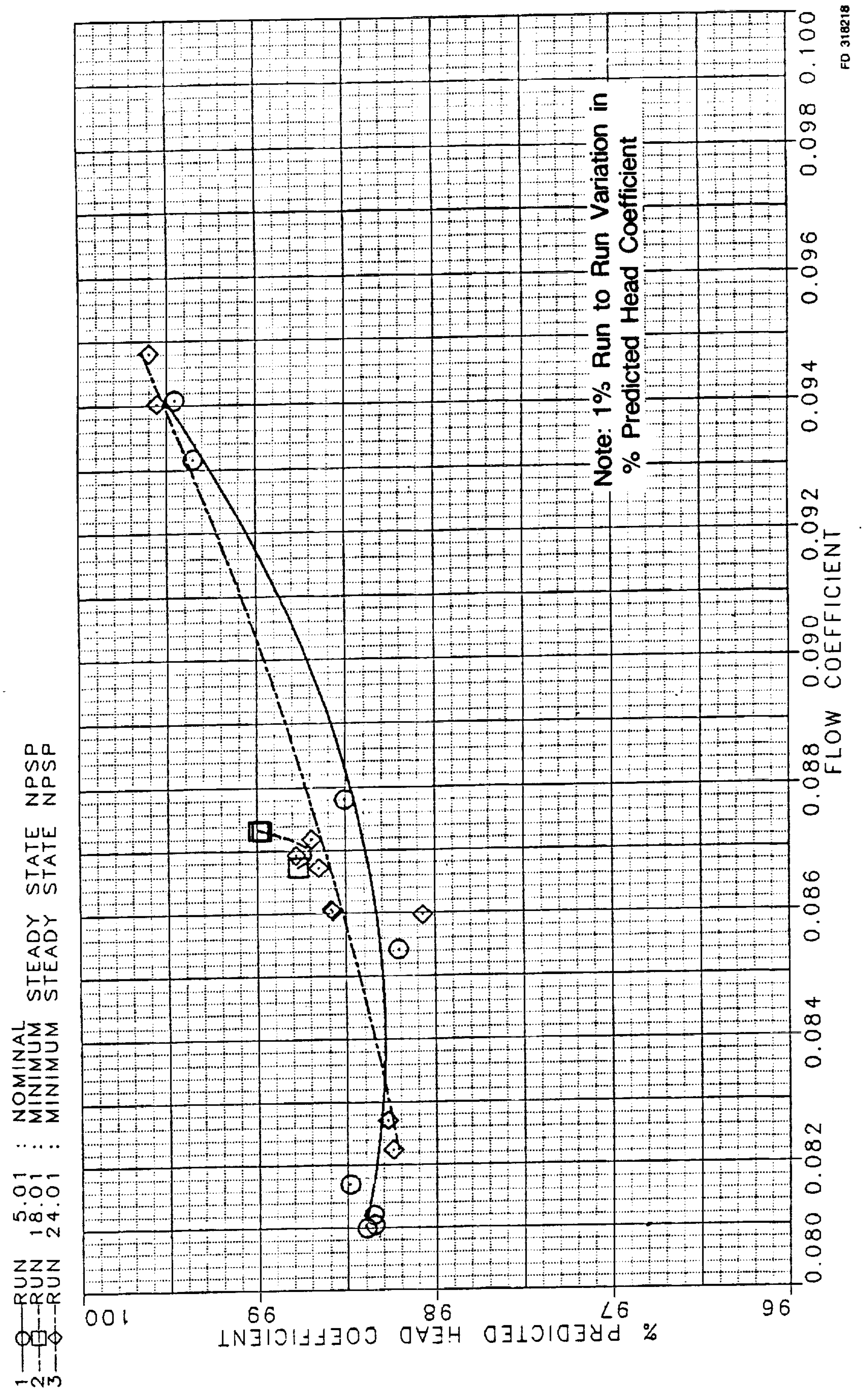

Figure V-59. Oxidizer Pump Performance

9046M

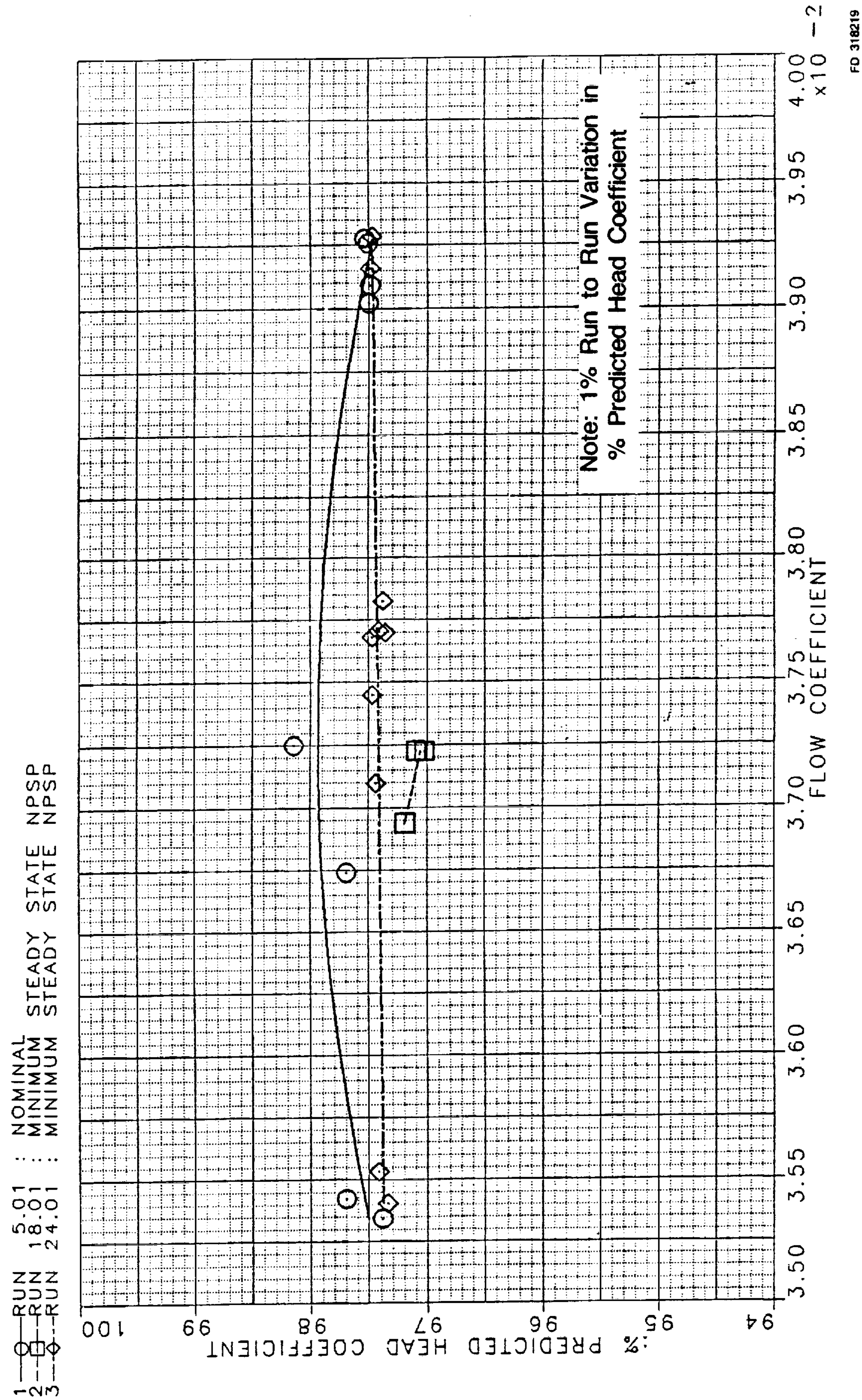

Figure V-60. Fuel Pump Performance

9046M

5.3.2 Effect of Mixture Ratio on Steady-State Operation

To determine the effect of mixture ratio during steady state operation, several runs completed mixture ratio excursions from 5.4 to 6.7. The effect of mixture ratio variation on steady state performance is presented in Figures V-50 to V-52, with the respective curves submitted for RL10A-3-3B Specification No. 2295. Data from several runs lie above the limits provided to the specification. This has been attributed to the trim run which operated toward the top of the limit box. With the permitted 1.5 percent run-to-run variation from the trim run, it is possible to exceed the limits provided to the specification. This could be avoided by operating the trim run through the center of limit box. These limits have been provided for RL10A-3-3B Specification No. 2295.

5.3.3 Tank Pressurization Flow Effects

The characteristics of the tank pressurization system were determined by analyzing the influence of tank pressurization on engine performance. Runs 4.01, 5.01, 24.01, and 25.01 operated with tank pressurization. The fuel cooldown dump line was open during Run 4.01 engine operation so the observed fuel flow is in error and has not been considered for this reason. The preliminary specification curve, of the effect of tank pressurization, submitted for the RL10A-3-3B specification, is presented in Figure V-53 with data from Runs 5.01, 24.01 and 25.01.

5.4 Aborts and Data Anomalies

5.4.1 Aborts

One run of the 23-run test program aborted and failed to accomplish its test objective. Run 14.01, a relight after a two-minute hold between firings, aborted 0.470 second after start. Minimum chamber pressure expected at this time is 8 psi, a 3 psi chamber pressure was measured due to a failure to light. Other engine runs have successfully fired at similar starting conditions and the reason for the no-light was not fully understood. This problem was discovered previously in Section IV-B-2. The objectives not met in Run 14.01 were accomplished in Run 22.01.

5.4.2 Data Anomalies

The shutdown performance deck would not execute for Runs 2.01 and 3.01. Iteration failures occurred due to faster oxidizer inlet valve actuation times caused by a missing orifice in the helium supply line to this valve. The effect of the decreased oxidizer valve actuation time on the shutdown performance deck was corrected, and shutdown performance analysis for Runs 2.01 and 3.01 was completed.

SECTION VI
ENGINE LIMIT TEST

Engine XR102-2 was selected to run the limit test per the Qualification Test Plan paragraph 5.0. The test was conducted on the E-6 test stand during hot run 44.01 on 12 April 1985. The engine was run with the thrust control chamber pressure tap vented to ambient which closes the turbine bypass, and the propellant utilization (PU) valve set at the highest mixture ratio position to simulate the most severe failure mode possible for the RL10A-3-3B engine. Figure VI-1 is a schematic of the system used to vent the thrust control.

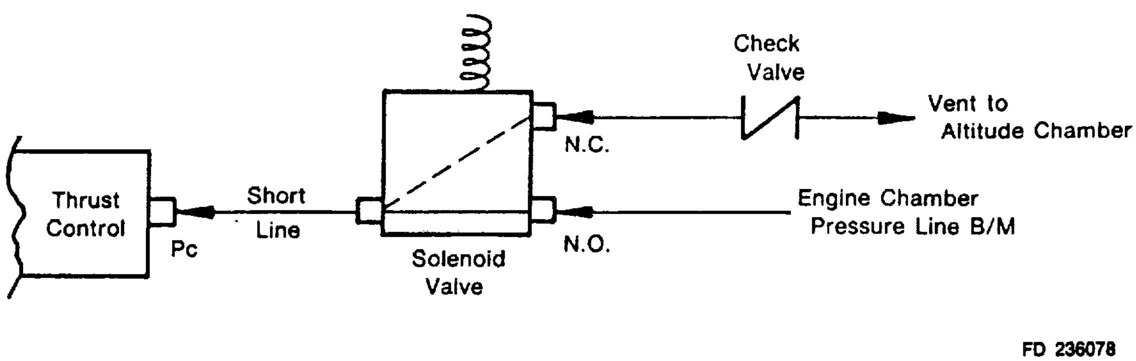

Figure VI-1. Schematic of System Used to Vent the Thrust Control

While making a calibration run with a PU valve excursion, the PU valve angle was set to obtain a mixture ratio of 6.65. After a 10-second stabilization period, the thrust control was vented to the altitude chamber. Thrust was 18,541 lb, mixture ratio was 6.24, and chamber pressure was 516 psia. After about 15 seconds the thrust control was returned to its normal position, and the PU valve was returned to the null position. The engine continued to operate satisfactorily and performance was unaffected. Post-test inspection revealed no problems with the engine.

The chamber pressure level achieved was the same as that reached in a similar test on the RL10-3-3A limit test. This pressure level is well below the maximum steady-state chamber pressure ever tested — 565 psia.

SECTION VII
TEARDOWN SUMMARY

The teardown of the Qual Test engine was completed as follows:

- The turbopump and components were removed from the chamber/injector.
- The chamber/injector was subjected to a production "green" turnaround per Production Engine Procedure RL10-04. No problems were found. Photos showing the generally excellent condition of the silver throat are shown in Figures VII-3 through VII-7.
- The turbopump was separated and the oxidizer pump and fuel pumps were completely disassembled. Since there was an unexplained shift in the fuel pump vibration characteristics on the last several runs of the engine, the teardown of the fuel pump was carefully scrutinized. The only notable anomaly was a low torque value on the turbine tiebolt (350 in-lb). Detailed inspection of all parts of the oxidizer and fuel pump showed them to be in excellent condition.
- All components were sent for CCS test. A small shift in thrust level could not be confirmed during CCS of the thrust control. All other CCSs were completed successfully.

A. DUAL PRESSURE SWITCH IGNITION SYSTEM

After successfully completing the Qual Test series the ignition system, BMT001, was sent for CCS test and successfully passed.

Inlet Valves Tig Weld Bellows

Both inlet valves with CKD10006 and CKD10004 also successfully passed CCS test. An individual teardown of each valve will be required to inspect and verify acceptable condition of the weld.

B. TURBOPUMP TEARDOWN

The following Table VII-1 provides a list of the major turbopump parts. The remarks indicate the results of a visual inspection and the recommended disposition of the part. The fuel pump and oxidizer pump parts were laid out and photographed. Figures VII-1 and VII-2 show the fuel pump and oxidizer pump respectively.

Table VII-1. Turbopump Parts List

Gearbox housing	2108766 S/N AIW323	Light wear at mating surface from turbine bearing housing. Reuse as is.
Fuel pump support plate	2131534 S/N BJA671	Top inner edge of plate scored from 1st stage impeller balance weight. Weight contacted plate during balance of the fuel pump. Weight was removed and placed in a correctly drilled hole in the 1st impeller. Reuse as is.
Fuel pump inducer	2105444	Some roughness on O.D. of blades due to rubbing -- reuse as is.
Turbine tiebolt	2072093	Reuse as is.
Spacer-Ring FP Impeller	2109360 Cla-2	Reuse as is.
Carbon seal carrier, turbine	2099982	Moderate scoring from spring. Reuse as is.
Spring, turbine bearing	2030549	Light wear on face and I.D. Reuse as is.
Fuel pump bearing nut (2)	2025276	Reuse as is.
Fuel pump bearing lockring	2095154	Reuse as is.
Turbine tiebolt spacer	2025959	Reuse as is.
Fuel pump tiebolt	2105443	Reuse as is.
Carbon seal plate, turbine	2099986	Light rub on seal face. I.D. scored from disassembly. Reuse as is.
Sleeve spacer	2029216 S/N 002	ID scored by repeated disassembly. Reuse as is.
Turbine bearing housing	2099981 Cla-1	Light wear on OD land. Recoat needed.
Lab seal-turbine	2106108	Very light rub in local area. Reuse as is.
Turbine exit stator	2100368 S/N BEW110	Very light knife edge rub. Reuse as is.
Fuel pump gearshaft assy	2099978 S/N BEZ738	Aft end on shaft was scored from tooling, during disassembly. Light wear on seal faces-moderate gear tooth wear.
Fuel pump impeller 2nd stage	2130328	Reuse as is.
Split ring 2nd stage impeller	2130507	Expendable.
Fuel pump impeller 1st stage	2099209 S/N BIS 576	Moderate tip rub. Reuse as is.
Turbine stator 1st stage	2129971 S/N BJH110	Reuse as is.
Turbine stator 2nd stage	2100364 S/N ACD2G	Reuse as is.
Turbine discharge housing	2100365 S/N ATR511	Very light scratches at bypass and turbine exit - Reuse as is.
Turbine rotor assy	2099990 S/N BIH20	Very light rub on 2nd stage K.E.s and interstage K.E.s. Reuse as is.

Table VII-1. Turbopump Parts List (Continued)

Fuel pump impeller housing	2108763 S/N ARB699	Moderate inducer and impeller tip rub. Reuse as is.
Turbine bearing spacer	2129718	Scoring on end due to disassembly. Reuse as is.
Fuel pump inducer tiebolt	2105443	Reuse as is.
Fuel pump bearing spacer	2130326 Cla-1	Galling from front bearing spacer, very light seal rub. Reuse as is.
Carbon seal, fuel pump rear	2088275 S/N BDF362	Carbon seal moderately worn. Reuse as is.
Carbon seal turbine	2106109 S/N BDF346	Carbon seal moderately worn. Reuse as is.
Carbon seal, fuel pump front	2034071 S/N 023	Very light wear. Reuse as is.
Carbon seal, fuel pump interstage	2105422 S/N BIK234	Very light wear. Reuse as is.
Bearing, turbine	2069342 S/N BID452	Ref QR 378463. Light wear on races, balls pitted and discolored. Rulon had moderate even wear.
Bearing, fuel pump	2069343 S/N BID397	Ref QR 378462. Very light wear, balls pitted. Rulon has moderate, even wear from inner race.
Seal holder, fuel pump interstage	2051510	Reuse as is.
Metering plug, fuel pump support plate	2131537 Cla-2	Reuse as is.
Plug, fuel pump support plate (2)	2030373	Reuse as is.
LOX pump housing	2099451 SL236761 CKD1719	Reuse as is.
LOX pump front bearing spacer	2056882	Reuse as is.
LOX pump front bearing nut	2071205	Reuse as is.
LOX pump rear bearing nut	2059451	Reuse as is.
LOX pump intermediate seal plate	2076271 S/N BKD101	Very light wear on seal faces. Reuse as is.
LOX pump bellows seal	2111006 BKD 9863 S/N BIM835	Very light wear. Reuse as is.
LOX pump bellows seal	2111006 S/N BIM836	Light wear. Reuse as is.
Carbon seal, accessory pad	2070916	Very light wear. Reuse as is.
Carbon seal housing, accessory pad	2102721 Cla-6	Light scratches from disassembly. Reuse as is.
Metering plug	2110359	Reuse as is.
Plug	2110360	Reuse as is.

Table VII-1. Turbopump Parts List (Continued)

Pin, idler gearshaft	2092685	Reuse as is.
Shaft, idler gear	2118349	Scored from repeated disassembly. Reuse as is.
Spacer, idler gear bearing (2)	2025415	Reuse as is.
Spacer, idler gear bearing	2025414	Reuse as is.
Idler gear	2073338 S/N 7L2105	Light wear on LOX gear side of teeth — there was some metal pickup. Moderate wear on fuel gear side of teeth — coating peeling away from balance removal area.
Bearing, idler gear (2)	2069344 S/N BID714 S/N BID610	 Normal wear. Normal wear — some spalling on race.
Bearing, LOX pump front	2069343 S/N BID395	Very light wear on balls and race. Very light rub on Rulon from inner race contact.
Bearing, LOX pump rear	2069345 S/N BID324	Moderate wear — cage scratched.
Elbow housing	2104486 S/N SP874	Reuse as is.
LOX pump tiebolt	2076265	First 3 or 4 threads have metal pickup should be replaced.
Carbon seal thrust ring (2)	2071203	Reuse as is.
LOX pump rear seal plate	2076272 S/N BHR192	Seal face plating has poor surface. Very light rub. Reuse.
LOX pump impeller	2126524 S/N BIH68	Very light scratches. Reuse as is.
LOX pump inducer	2126523 S/N BIH120	Blades have light scratches. Lab seal knife edges light rub. Reuse as is.
LOX pump front seal plate	2073314 Cla-1	Very light seal rub I.D. Scored during disassembly. Reuse as is.
LOX pump inducer bolt	2105445	Reuse as is.
Split carbon seal housing	2108160	O.D. light scratches - normal carbon deposits on I.D. Reuse.
LOX pump inducer housing	2181436 S/N BMA24	Light to moderate rub all around. Reuse as is.
LOX pump gearshaft assy	2110457 S/N BEZ728	Light even wear - coating removed. Reuse as is.
LOX pump carbon seal ring (2)	2108161	Normal wear. Reuse as is.

Major Parts List

Name	*P/N*	*S/N*	*Remarks*
Chamber/injector assembly	2180696F	ACB888	Green run turn around completed and acceptable.
Fuel pump assembly	2135710	600524	See Turbopump Parts List.
LOX pump assembly	2181415	600524	See Turbopump Parts List.
Oxidizer flow control	2119340	BKW759	Passed CCS.

Table VII-1. Turbopump Parts List (Continued)

Major Parts List

Name	*P/N*	*S/N*	*Remarks*
Solenoid (3) Start	2085703	600580	Passed CCS.
Lox	2085703	600578	Passed CCS.
Fuel	2085703	600574	Passed CCS.
Lox inlet shutoff valve	2183704 CKD 10004	BGP140	Passed CCS.
Fuel inlet shutoff valve	2185908 CKD10006	8L3793	Passed CCS.
GOX valve	2075301	626127	Passed CCS.
Main fuel shutoff valve	2112399	600523	Passed CCS.
Gimbal Assembly	2183571 SL 240445	BMC94	Reuse as is.
Interstage cooldown valve	2183571	600520	Passed CCS.
Pump discharge cooldown valve	2106435	600523	Passed CCS.
Igniter	2183710	BMT001	Passed CCS.
Thrust Control	2105497	607147	Passed CCS.
Transducer box	2185705 SL 239303	BIS 569	Reuse as is.
Pump discharge line	2084308	N8702	Reuse as is.
Jacket inlet line	2118223	AHA 883	Cla-4. Reuse as is.
Venturi line	2108120	BFT 112	Reuse as is.
Turbine discharge line	2099716	SP 844	Spec. Instr. Line. Reuse as is.
LOX injector inlet line	2060588	9L-3198	Reuse as is.
Speed pickup	2064388	4529-008	Reuse as is.
FTIT probe	2100815 Model 134GR	BIH250	Resuse as is.
FPHT probe	2114950 Model 177BR	BLG 483	Reuse as is.
OPHT probe	2114950 Model 177BR	BLG 467	Reuse as is.

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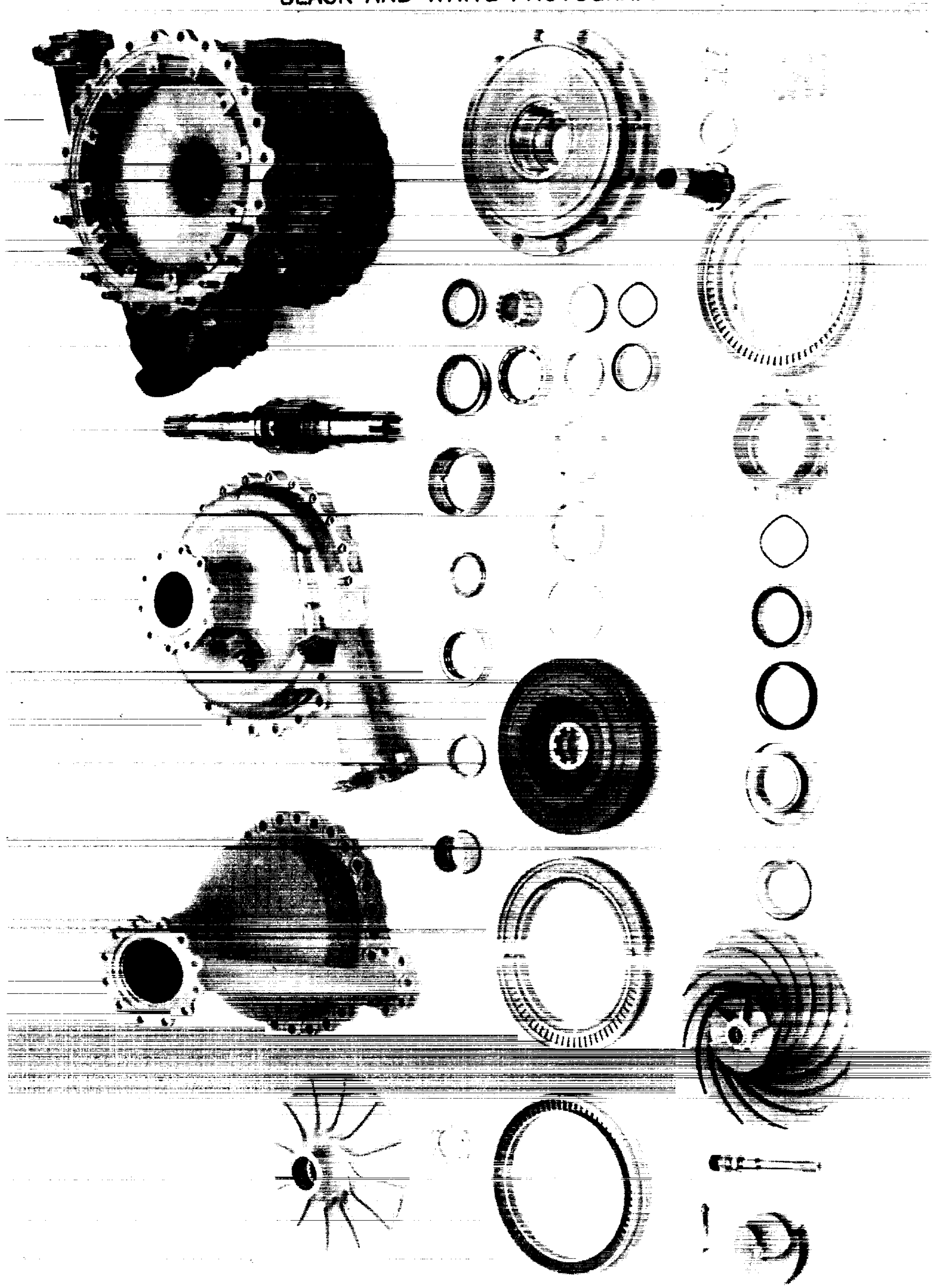

Figure VII-1. Fuel Pump Parts

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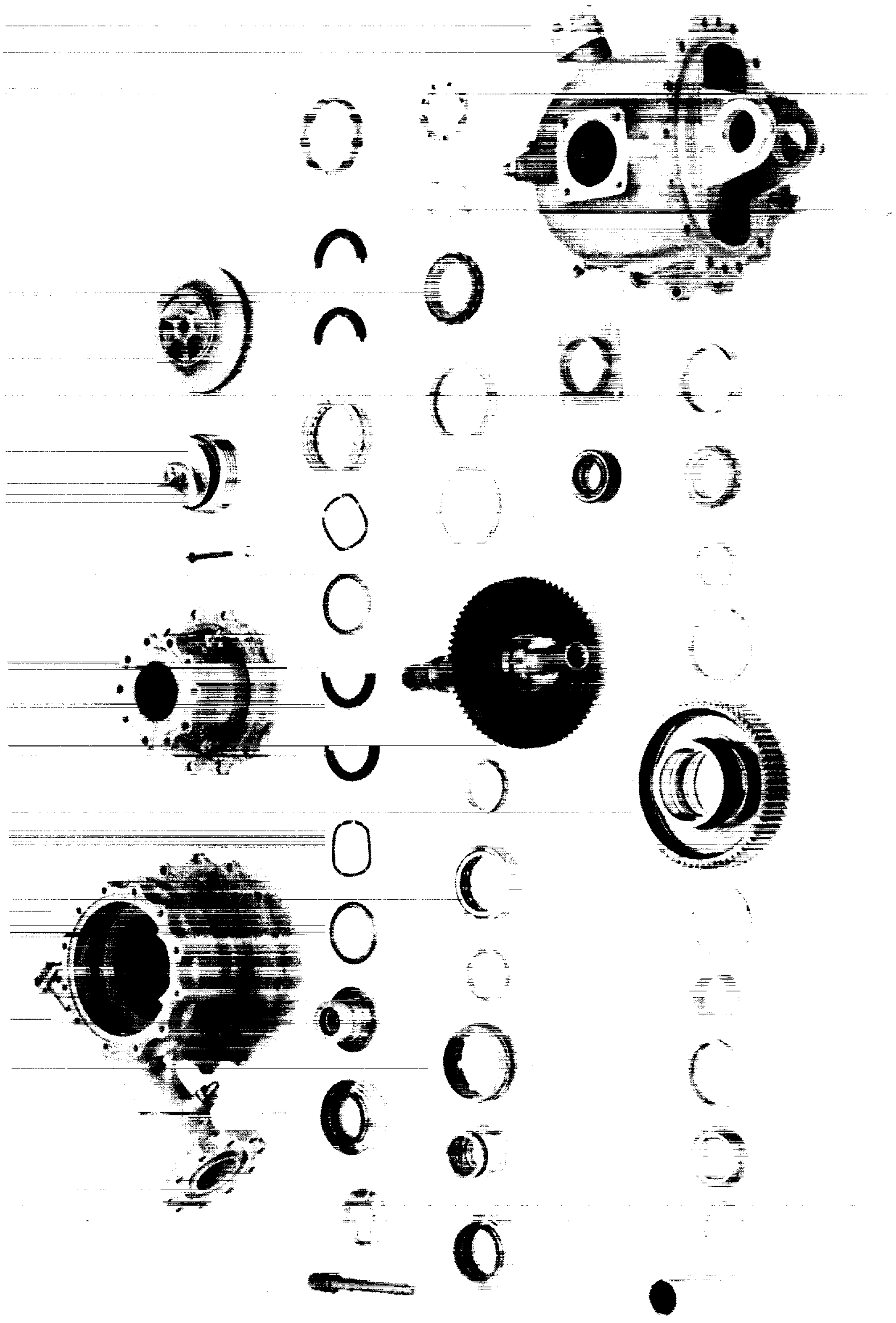

Figure VII-2. Oxidizer Pump Parts

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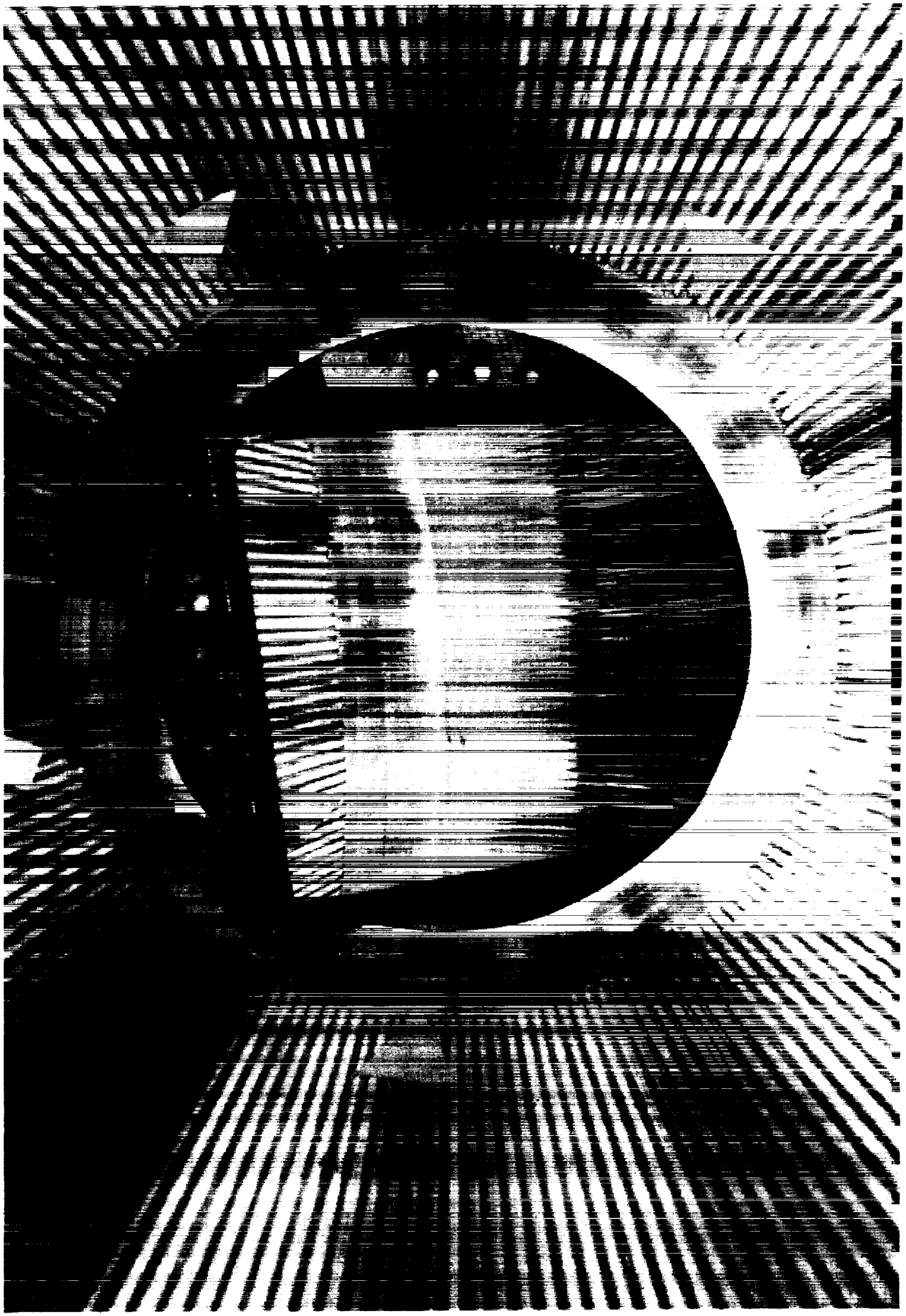

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Figure VII-3. Post-Run Photo of Silver Throat Insert

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Figure VII-4. Post-Run Photo of Silver Throat Insert

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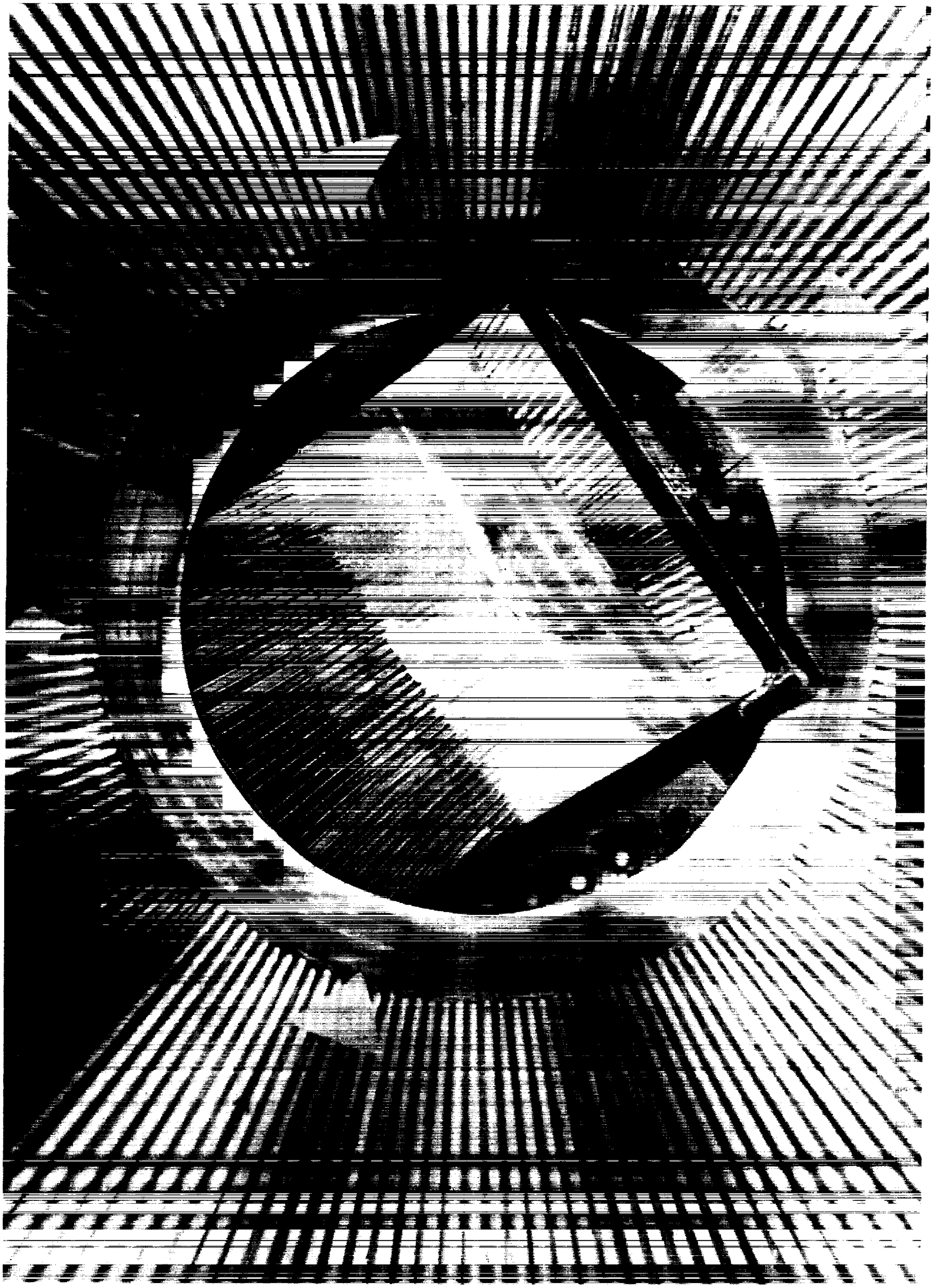

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Figure VII-5. Post-Run Photo of Silver Throat Insert

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Figure VII-6. Post-Run Photo of Silver Throat Insert

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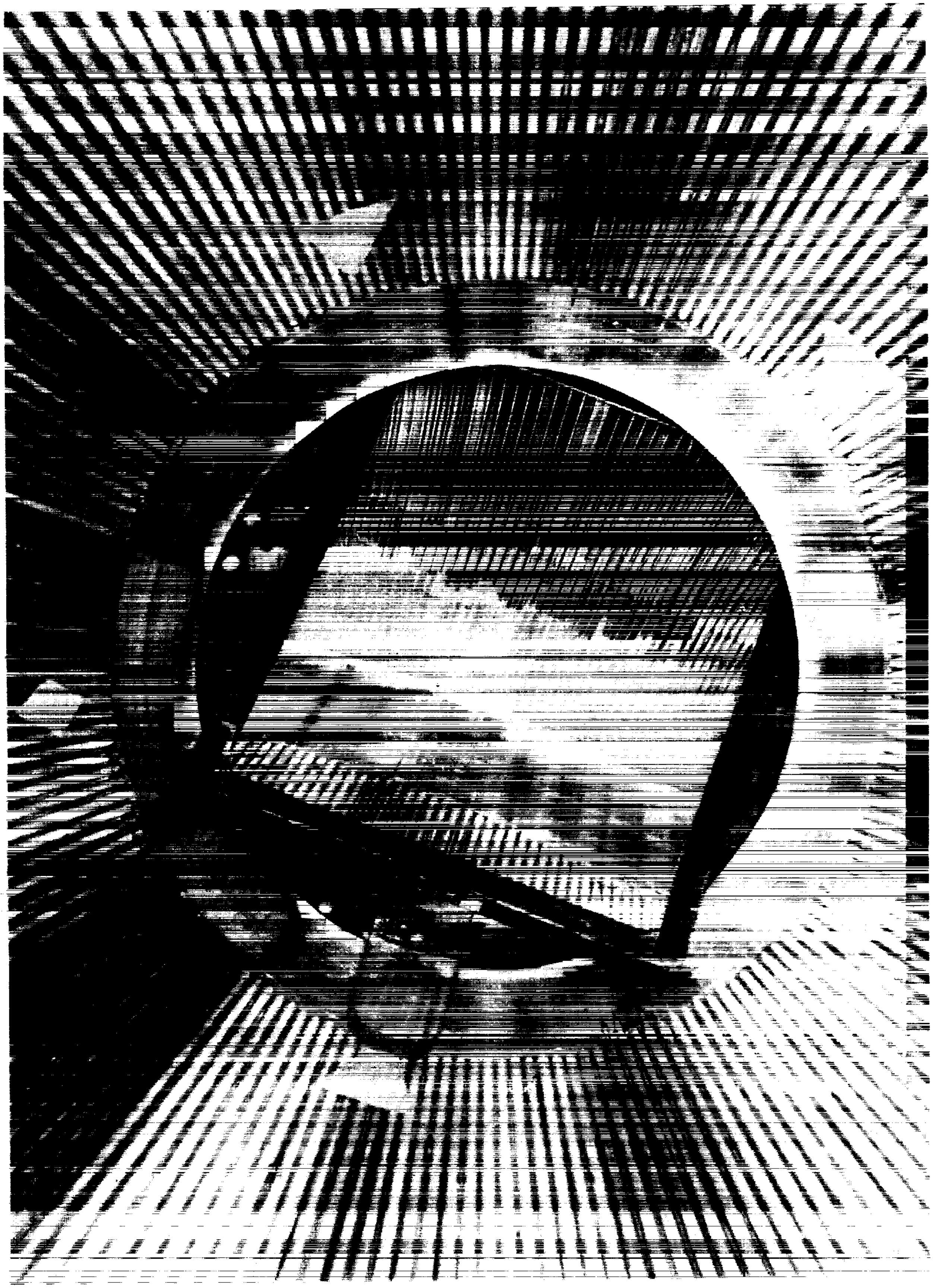

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Figure VII-7. Post-Run Photo of Silver Throat Insert

SECTION VIII
CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The RL10A-3-3B engine is qualified for operation at the higher mixture ratio of 6.0 ± 0.7. This is based on the fact that the engine operated successfully under all conditions required by Spec 2295 and the hardware showed no detrimental effects from operating at the higher mixture ratios.

An ignition problem has been uncovered and relates to the Shuttle/Centaur inlet conditions and the small cooldown area used in the oxidizer flow control. For Shuttle/Centaur operations the most efficient means of cooldown is achieved by using this small flow area and it is desirable to keep this configuration. Prior to qualifying the RL10A-3-3B engine for use on the Shuttle/Centaur an improved ignition system must be qualified to eliminate the no-light problem.

B. RECOMMENDATIONS

If the RL10A-3-3B engine is to be used in the Shuttle/Centaur, a new ignition system must be designed, built and qualified.

If the RL10A-3-3B engine is to be used in ground-launched vehicles the large cooldown area oxidizer flow control (with bypass) should be reinstated, and the ignition characteristics will be the same as the RL10A-3-3A engine, assuming the start inlet boxes are similar.